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DEVELOPMENT OF THE BALLISTIC SUBSYSTEM FOR AN IN-FLIGHT ESCAPE SYSTEM FOR THE AH-1 COBRA HELICOPTER

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FOREWORD

Helicopters which crash often carry the occupants to their death. Over half of those who have died in AH-1 crashes could have survived given some means of escape before ground impact. The Naval Surface Weapons Center, Dahlgren Laboratory (formerly Naval Weapons Laboratory) Technical Report TR-2627 of October 1971 reported the work done in demonstrating the feasibility of providing such an in-flight escape system (IFES) for the AH-1 Cobra helicopter. The report also recommended that a development program be established to retrofit the AH-1 helicopter with an IFES.

A program sponsored jointly by the U. S. Army Aviation Systems Command, Development Division, Department of the Army, St. Louis, Missouri and the Naval Air Systems Command, AIR-531, Washington, D. C. was established and in April 1972 NSWC/DL received funding (PO-2-0111) from the Naval Air Development Center, Warminster, Pennsylvania to begin effort on the ballistic subsystem for a Cobra IFES. The ballistic subsystem effort is described herein.

This report was reviewed by:

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ABSTRACT

The Naval Surface Weapons Center, Dahlgren Laboratory, was responsible for development of the ballistic subsystem of an in-flight extraction escape system which is to be retrofitted into the AH-1 helicopter.

Work was done in the following areas of the ballistic subsystem: (1) rotor blade severance, (2) canopy jettison, (3) gunsight retraction, (4) launcher for the extraction rocket, (5) lap belt release, and (6) initiation, sequencing and energy transfer. Also a computer program was prepared to simulate the extraction of the crewmen from the stricken helicopter. It was demonstrated that (1) the canopy can be jettisoned at aircraft speeds up to 170 knots, (2) rotating rotor blades can be severed both in a hover mode and at 150 knots forward speed, and (3) the extraction rocket can be launched successfully at speeds up to 150 knots.

The trajectories of the crewmen were mathematically simulated and data generated were used in extraction tests. A design of an initiation, sequencing and energy transfer assembly was prepared using off-the-shelf components where possible. The design of the assembly will allow it to be retrofitted into the AH-1 with minimum changes required to the aircraft.

CONTENTS

INTRODUCTION

Helicopters which crash often carry the occupants to their death. Over half of those who have died in AH-1 crashes could have survived given some means of escape before ground impact.

In March 1971, the Naval Surface Weapons Center, Dahlgren Laboratory, (NSWC/DL) initiated a study to investigate the feasibility of retrofitting the AH-1 helicopter with an in-flight escape system (IFES). This study, reported in NSWC/DL Technical Report TR-2627, concluded that the best candidate for such an escape system was one which utilized an extraction rocket. A joint Army-Navy IFES program was established in April of 1972 in which the Naval Air Development Center (NADC), Warminster, Pennsylvania was assigned as lead laboratory and NSWC/DL was assigned responsibility for development of the ballistic subsystem of the in-flight escape system.

Figure 1 is a photograph of the AH-1G and AH-1J helicopters. The AH-1G is a single engine helicopter flown by the Army while the AH-1J is a twin engine helicopter flown by the Marine Corps. Another AH-1 model involved in this program was the AH-1Q which is basically an AH-1G which has been modified to accept the TOW gunsight.

The IFES for the AH-1 was divided into two primary subsystems, with one being the escape subsystem and the second being the aforementioned ballistic subsystem. In addition to working on the ballistic subsystem NSWC/DL also provided assistance in the escape subsystem portion.

NSWC/DL was directly tasked to do work in the following seven areas:

1. rotor blade severance
2. canopy jettison
3. gunsight retraction
4. launcher for the extraction rocket
5. lap belt release
6. initiation, sequencing, and energy transfer
7. computer simulation of the trajectory of the crewmen after extraction from the helicopter.

In items 1 through 4 and 6, NSWC/DL was to design and develop all required hardware which when integrated would provide the ballistic subsystem for the in-flight escape system. Also, NSWC/DL was to be responsible for the qualification for service release of all ballistic items for both the escape and ballistic subsystems.

Because the Navy in-house development effort was terminated by NAVAIR prior to completion of the development phase, no integrated ballistic system tests were conducted. Therefore, this report covers only the development work that was accomplished and the tests that were conducted on each item.

During the development effort items 1 through 6 were treated as discrete work elements; the remainder of this report is divided into sections covering each of these six areas, in the order shown above. All figures referenced in each section are located at the end of that particular section.

The work done by NSWC/DL in the computer simulation area, item 7, is reported in NSWC/DL Technical Report TR-3123 of May 1974.

AH-1G

AH-1J

Figure 1

ROTOR SEVERANCE ASSEMBLY

BACKGROUND

The functional requirement of the rotor severance assembly was to provide a safe egress path for the extractees by removing the main rotor blades and the upper section of the main mast. The assembly had to provide a sequencing capability to project the severed blades in a predetermined and predictable direction, thereby presenting the least danger to the crewmen and neighboring aircraft. A redundant backup initiation mechanism also was to be provided to reduce the chances of malfunction. Finally, the assembly could not degrade the helicopter's flight envelope or the execution of its mission.

The design approach used was divided into the following areas:

1. Develop methods of energy transfer to the blade severance assembly.

2. Develop techniques for controlling initiation of blade severance charges relative to angular position of the blades, thereby controlling the initial trajectory of the severed blades with respect to the helicopter.

3. Develop techniques for severing the rotor blades at yoke and mast.

METHODS OF ENERGY TRANSFER

To sever the main rotor blades, the explosive charges must be attached directly to the rotor yoke (3, Figure 2) and mast (7). The energy to initiate these explosives must be transferred from stationary to rotating members of the transmission and mast assemblies. The problem with transferring energy to the mast lies in the dynamics of the AH-1 transmission components. As the blades (1) rotate, the swashplate outer ring (12) and scissors and sleeve assembly (9) also rotate. Simultaneously, the collective lever (14) and swashplate and support assembly (13) move vertically to control the main rotor pitch. This combined, relative motion along with the motion of the pitch change tubes (8) makes access to the main mast particularly difficult.

There were two approaches considered that would avoid the problems encountered with the transmission dynamics. The first was an external method wherein the energy transfer is effected through a spinner and transmission cowling contact. The spinner (10, Figure 3) rotates with the main mast and has an interface with the cowling.

Energy would be transferred from the point of initiation back along the cowling to the spinner. If the system was electrical, a simple brush contact could accomplish energy transfer to the spinner. In a ballistic system, a detonation wave could be transferred across the air gap between the cowling and the spinner. Once this transfer is accomplished, energy is transmitted along the outside of the mast to the explosive charges on the yoke and mast.

The second method was an internal energy transfer method whereby the energy transfer is accomplished through a slip ring (7, Figure 4) mounted to the bottom of the rotating mast nut (1). The transfer lines go from the point of initiation to the bottom of the transmission and then up the inside of the mast through the standpipe (9) to the slip ring and on to the charges via the mast trunnion junction box. If the system was ballistic, confined detonating cord would transfer energy to the ballistic slip ring. The ballistic slip ring would transfer explosive energy across an air gap to confined detonating cords (CDC) leading to the mast and yoke charges. In an electric system, the slip ring would consist of a set of brushes which rotate around a stationary band. Electrical energy is conducted from the point of initiation through the slip ring to the charges.

The internal method had several important advantages over the external approach. Location of the slip ring in the internal method is inside the main mast and is therefore shielded from any adverse exposure to the elements, including HERO (Hazards of Electromagnetic Radiation to Ordnance). The external spinner method would require more extensive development and aircraft modifications and would have the added requirement of protecting the spinner-cowl interface from dust and rain. The energy transfer lines along the cowling would also be more exposed to enemy fire. The internal transfer method eliminates this problem to a large extent because the lines are shielded by the transmission. Based upon these advantages, it was decided to pursue the internal energy transfer method.

It was also determined that the assembly should be electric rather than ballistic. There are several advantages in using an electric transfer method over a ballistic one. The electrical approach would be of low technical risk due to utilization of existing hardware. The electric slip ring and standpipe are included in an optional blade tip lighting system used on some AH-1J helicopters. The components required for the ballistic transfer would require costly design and qualification programs and could be incompatible with the blade tip lighting system. The electrical method will also provide better control over the direction of travel of the severed blades as it provides a more accurate means of controlling the point of rotor charge detonation. A ballistic transfer would be subject to the tolerance of the confined detonating cord detonation velocity. In effect, this would increase the area in which severed blades might travel. An electric assembly is also more advantageous from a safety standpoint because the circuit can be routinely checked with a simple volt meter. A break in a ballistic line, however, could not be detected until initiation is attempted.

METHODS OF CONTROLLING THE POINT OF INITIATION

A design requirement of the rotor severance assembly is that the severed rotor blades present no danger to the extractees or to other aircraft flying in formation. To achieve this result, it was initially decided to sever the blades so one travels forward while the other travels rearward of the aircraft. But it was also a requirement that their trajectory might have to be other than fore and aft. The only practical way to control the path of the blades is to control the point of severance so that the blades angular momentum will carry them in the desired directions. This was accomplished in the previously mentioned electrical assembly by segmenting the slip ring bands so electrical contact is made only when the blades are in the proper orientation.

After conducting tests with the slip ring it was found that when the mast nut was torqued to its proper value the live slip ring segments could not be correctly positioned. The proper positioning of these segments was necessary prior to being able to determine where the blades would be upon severance.

In order to resolve this problem modifications were made to the existing standpipe assembly. The method of locking the standpipe to the base of the transmission housing in those AH-1J's equipped with blade tip lights is a retaining stud (8, Figure 4) which passes through a hole in both the transmission housing and the standpipe plug. The standpipe plug was modified as shown in Figure 5. With this design the slot allows the standpipe to be rotated after the mast nut is installed. By this rotation the slip ring segments can be correctly positioned. After the standpipe is positioned the locking nut and bolt are tightened and the knurl on the steel nut engraves into the aluminum plug preventing rotation.

From tests it was determined that if the blades were to be sent in a fore and aft direction with respect to the helicopter longitudinal axis the live slip ring segments had to be on an axis rotated 90° from the longitudinal axis (angular momentum of the blades when rotating at approximately 300 RPM rotates them approximately 90° from the location at which they are severed).

In effect the slip ring acts as a switch constantly opening and closing as the blades rotate. Current is not applied until the escape system is initiated and then is not carried on to the charges until the blades are in the proper orientation. The accuracy in programming the blade trajectory is then limited only by the firing characteristics of the LSC detonators. If the firing time of the detonator is short, the width of the live slip ring segments can be narrow. This in turn will narrow the sector in which the blades will be cut thereby narrowing the sector in which they initially travel after severance. The primary band will be segmented in two diametrically opposite positions so there will be two severance opportunities per revolution. A second, completely independent non-segmented band will be provided for a backup firing circuit which, when activated by the energy transfer assembly, will provide a continuous firing impulse. This firing impulse will occur after a 100 millisecond delay (the time required for the blades to make one-half revolution at 300 RPM and pass through an initiation point) and at this time the blades will be severed regardless of their orientation. Each of the two electrical initiation assemblies employs redundant detonators and independent circuitry.

TECHNIQUES FOR SEVERING BLADES AT YOKE AND MAST

There were several safety factors to be considered in locating the points of severance. The most important were:

1. Reliability - The blade assembly should be cut in such a manner that the severance will not be dependent on the rotational speed of the blade because relying on such a factor to aid in severance would seriously limit the system. It would also be advantageous to minimize the number of places cut, thereby eliminating dependence on several events to function simultaneously.

2. Ease of Energy Transfer to Charge - To minimize the danger of initiation failure due to breaks in energy transfer lines, it would be desirable to sever at a location which has little motion relative to the mast nut.

3. Minimization of Explosive Required - By carefully selecting the area to be cut the explosive charge could be significantly reduced.

4. Least Danger to Crewmen - Charges should be located in a position which would minimize the danger of shrapnel, blast effects, and noise level to the crewmen.

5. Ease of Installation and Inspection - Charges should be located in a position that would be easily accessible to minimize installation and inspection time.

The requirement to remove the upper section of the main mast to prevent the crewmen from striking it upon extraction dictated one severance point. This charge was located 30 inches below the top of the mast and would remove all of the mast above the cowling. Additionally, by severing the main rotor hub, the blades would be made to travel away from the helicopter in opposite directions due to their angular momentum. With this cutting technique the severed section of the mast will be carried away with one of the blades. The reason for not keeping the blades attached to the mast as a unit was that they would rotate unstably around some center of rotation and their behavior would be random. Several methods were considered in effecting this second severance. Briefly, they were (a) remove one of the main blade bolts (20, Figure 6) which would allow the blade to travel in one direction while the entire rotor hub, severed mast section, and remaining blade travel in the opposite direction; (b) sever the yoke extension bolts (3) on one blade to allow the yoke, blade and mast section to travel together while the remaining blade and its blade grip travel in another direction; (c) sever the yoke assembly itself, 5 inches from the extension bolt centers (same effect as method (b) but would require a single charge); (d) sever the yoke assembly in two equal parts at the trunnion (4, Figure 2); and (e) sever the blade retention strap (1, Figure 6) and remove the grip nut (15) to have the blade and blade grip (13) travel as a unit while the remaining blade and yoke assembly would make up the second unit.

The location finally selected for the second point of severance was that of method (c). This location was the more advantageous for several reasons. A single charge could be employed here while two separate charges would be required for methods (b), (d), and (e) above. The use of a single charge would increase safety by minimizing areas of possible failure, and would eliminate the problem of coordinating the detonation of two charges. Charge size minimization was also important in deciding to cut the yoke assembly. For this reason, the concept of removing the main blade bolt proved impractical in early tests. An explosive charge was placed inside the hollow main blade bolt which holds the blade to the blade grip. It was hoped that the charge detonation would sufficiently weaken the bolt to allow the blade's momentum to carry it away from the helicopter. This concept was tested statically, with unfavorable results, because confinement of the blade structure (at this point the blade is solid steel) was so great that insufficient damage was done to the bolt to insure that the blade would be carried free. Ease of energy transfer was another factor which led to the final decision. Energy transfer to the main blade bolt and to the retention strap would be complicated by the pitch change motion of the blades and blade grip.

The constant flexing of the lines could lead to loose connections in an electrical assembly or a broken explosive train in a CDC assembly. On the other hand, the yoke assembly had little motion relative to the mast nut, lessening to an extent the transfer problem.

Summarizing, the blade assembly was to be cut in two locations. The main mast would be severed 30 inches from the top, and the yoke assembly would be severed 5 inches from the extension bolt centers. There would be no charge designed to sever the standpipe (9, Figure 4) or the pitch change tubes (9, Figure 3). The standpipe is a thin aluminum tube (.049 inch wall) and will be sheared easily by the main mast as it is carried away. The pitch change tubes are cast aluminum and also will be sheared by the exiting mast assembly.

HARDWARE DEVELOPMENT, EXPLOSIVE SELECTION AND CHARGE OPTIMIZATION

Once the points of severance were determined, the problem became one of hardware design and charge optimization. The yoke assembly presented the greater difficulty due to its physical dimensions. It is forged 4340 stainless steel, 0.600 inch thick and 14 inches wide. The main mast is a 4340 stainless steel tube. At the point of severance, it has a maximum wall thickness of .435 inch for the AH-1G and .595 inch for the AH-1J. Both the yoke and mast had been severed in an earlier feasibility study for this in-flight escape system as reported in the NSWC/DL Technical Report TR-2627. The yoke assembly was cut with a commercial linear shaped charge (600 grain/ft copper sheathed with RDX explosive core) (Figure 7) and the AH-1G mast was severed with a linear shaped charge (Figure 8) developed at NSWC/DL (200 grain/ft composition C-4 loaded ring with a stainless steel liner). Although both devices performed satisfactorily, they were unacceptable as a final design because RDX is too sensitive and composition C-4 will not withstand the required temperature environments.

Two approaches were pursued concurrently in the development of devices to be used in the final design. One approach was to investigate commercially available linear shaped charges and the other was to develop a shaped charge in-house. Due to sensitivity requirements of MIL-STD-1316A, choice of explosives was limited to commercially manufactured HNS and DIPAM. HNS was more suitable than DIPAM for linear shaped charge applications due to its higher detonation velocity. The in-house development would use castable PBXN-101 in the final design.

Since a device to sever the mast was previously designed, early development was centered on the yoke charge. Using the 600 grain/ft

RDX charge as a guideline, 600 and 700 grain/ft aluminum and copper sheathed HNS loaded linear shaped charges were purchased and tested. However, after several tests to optimize charge standoff, the maximum penetration achieved was only 50 percent using a 700 grain/ft copper sheathed charge. The design requirement was full penetration of the assembly in a static, unloaded condition. Based on these results, the projected HNS load required for full penetration seemed excessive.

Effort was then concentrated on the in-house development with copper and annealed stainless steel liners being tested. The liner thickness and width were varied as were standoff distance and explosive load. To minimize loading time, charges were first loaded with C-4 because the explosive output of C-4 and PBXN-101 are comparable. Final results indicated that the yoke assembly could be consistently severed (Figure 9) with 1,000 grain/ft PBXN-101 loaded LSC with a copper liner 0.032 inch thick. Figure 10 shows the cross section of the charge housing and liner. As mentioned previously, a 200 grain/ft C-4 LSC ring with a .018 inch thick stainless steel liner was used for mast severance in the feasibility study. This design was finalized and consistently severed the AH-1G mast (Figure 11). However, when loaded with PBXN-101 and fired against the thicker AH-1J mast only 70 percent penetration was achieved. It is believed that this charge is sufficient to completely sever the AH-1G mast and that only a small increase in charge is required to sever the AH-1J mast. All loading of the PBXN-101 was performed by the Naval Weapons Station, Yorktown, Virginia.

Once the charges were developed, the problem of securing them to the yoke and mast was addressed. Several methods of attaching the yoke charge were considered but either because of the vibrational problems or the stress concentrations which would be introduced with most of the methods it was decided by Bell Helicopter Co. that clamping the charge directly to the yoke was the best method. Hardware using this technique (Figure 12) was statically and dynamically tested.

Securing the LSC ring to the mast also became a problem due to the lack of existing fixtures on the surface of the mast. The fastening concept seen in Figure 13 was also submitted to the Bell Helicopter Co. and was given approval. This technique consisted of bolting the two charge housing halves together around the perimeter of the mast. On both the yoke and mast charges it was planned that in addition to the mechanical method of attachment a RTV rubber compound would be used to both weatherproof the charges and provide additional holding strength.

An important feature included in both the yoke and mast charge designs is the provision for independent primary and auxiliary detonation. The yoke charge assembly has two detonation points and the ring charge has one primary and one auxiliary port for each ring half. These detonators would be powered with independent circuitry, including separate bands on the slip ring. Figure 14 shows the final configuration of both the yoke and mast charges installed. The wire coming from the top of the mast nut goes into the junction box which is bolted to the trunnion. From the junction box wires are then routed to the detonators for the yoke and mast charges.

The weight of the hardware was also a major design factor. A weight breakdown for the rotor severance assembly is included below. It should be noted that a standpipe and a slip ring are currently in service as part of the blade tip light system on the AH-1J helicopter and their weights therefore should not be included as part of the extraction system for the J model.

TABLE I

Item	Weight (lbs)
Ring Charge Assembly (Loaded)	1.30
Yoke Charge Assembly (Loaded)	1.36
Yoke End Clamps (2 @ .40)	0.80
Standpipe	2.28
Slip Ring	1.43
TOTAL WEIGHT	7.17

SUMMARY OF TESTS

Approximately 70 static tests were conducted at NSWC/DL in the development of the rotor severance assembly. Based on the results of these static tests two dynamic blade severance tests were conducted at the Naval Air Test Facility (NATF), Lakehurst, New Jersey and the effectiveness of the assembly was demonstrated.

The first dynamic test, a tie down test, was conducted in July 1972. The helicopter was placed in the hover mode and the blades were rotated at approximately 300 RPM. The test was successful and provided the following conclusions:

1. The rotor blades can be removed from the egress path without presenting any danger to the crewmen being extracted.

2. The explosives can be detonated electrically through the slip ring.

3. The slip ring can be used as a programmer to control the sector in which the blades will travel. In this test the blades were sent in a fore and aft direction.

4. The LSC appears to present no blast or shrapnel hazard to the crewmen.

The second dynamic test was a sled test and occurred in July 1973. The helicopter was given a forward velocity of 150 knots and the blades were rotated at 325 RPM. To eliminate the danger of the vehicle running over a severed blade, the blades were programmed to travel starboard and port rather than fore and aft. This test was also successful and it presented the following conclusions:

1. Dynamic effects of the air stream did not hinder the removal of the blades from the egress path.

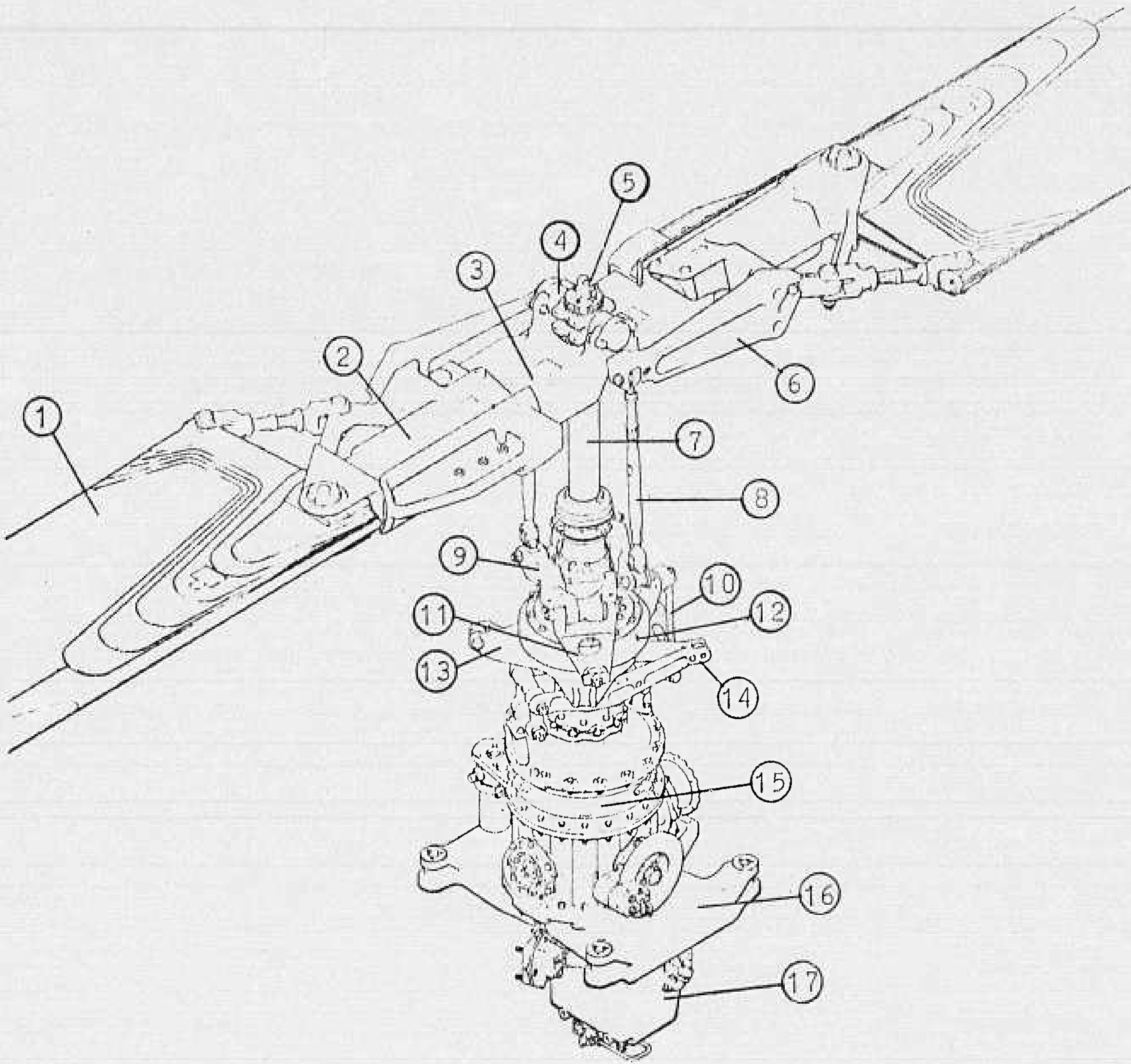
2. Dynamic effects of the air stream did not hamper the ability of the assembly to program the direction in which the severed blades will travel.

3. Again there appeared to be no blast or shrapnel hazard to the crewmen.

It should be noted that while these tests used a final design standpipe and slip ring the explosive charges were not then fully developed. Instead 600 grain/ft RDX and 200 grain/ft C-4 were used in the yoke and mast charges, respectively. Since these tests were conducted the PBXN-101 yoke charge development was completed and the charge was successfully tested using the electric detonators as the initiation source. A PBXN-101 ring charge was also tested and with optimization of the explosive charge, its design could also be frozen. The use of these charges will not alter the performance of the assembly as demonstrated in the two dynamic tests.

RECOMMENDED ACTION

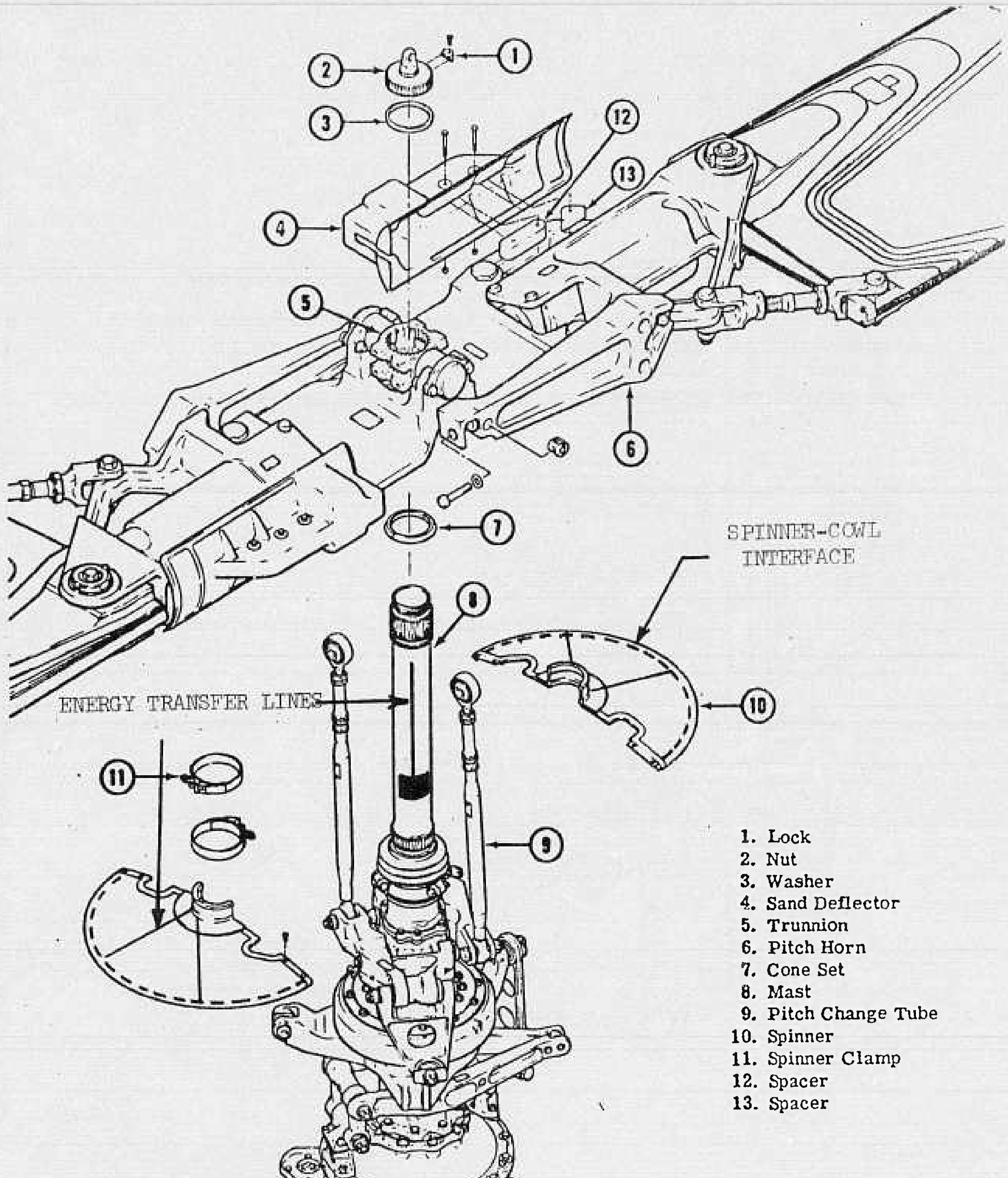
As mentioned above, the ring charge is not fully developed. Tests revealed that the charge did not fully sever the thicker AH-1J mast. The immediate step in the development of the assembly is to finalize this charge. It is believed that an increase in the charge is all that is required and no changes in the liner design are necessary. Once this is accomplished, all that remains is to finalize the PBXN-101 loading techniques begun in conjunction with NWS Yorktown.



1. MAIN ROTOR BLADE
2. BLADE GRIP
3. YOKE
4. TRUNNION
5. RETAINING NUT
6. PITCH HORN
7. MAST
8. PITCH CHANGE TUBE
9. SCISSORS AND SLEEVE ASSEMBLY
10. ANTI-DRIVE LINK
11. DRIVE LINK
12. SWASHPLATE OUTER RING
13. SWASHPLATE AND SUPPORT ASSEMBLY
14. COLLECTIVE LEVER
15. TRANSMISSION
16. SUPPORT CASE
17. ACCESSORY DRIVE AND SUMP CASE

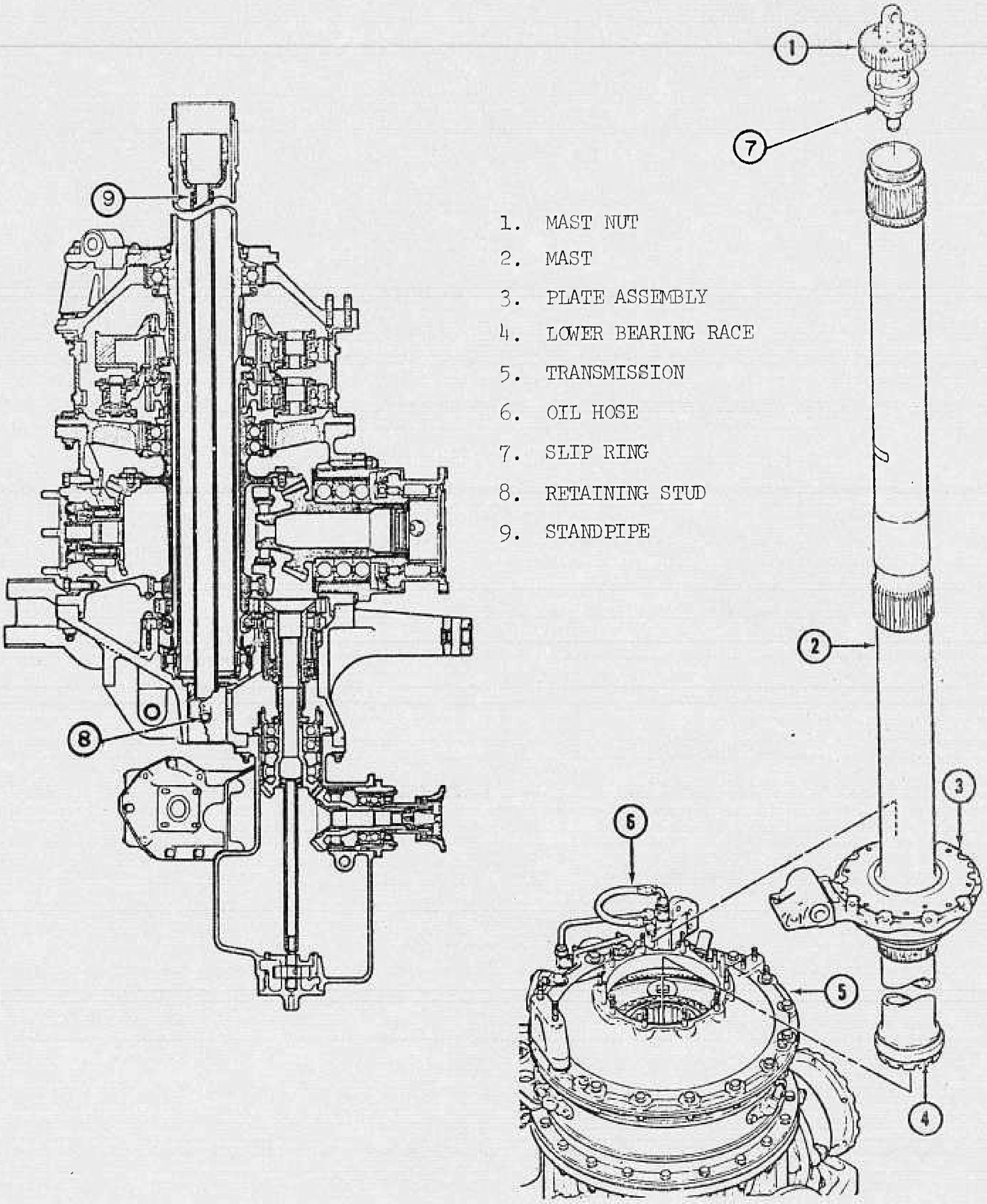
Main Transmission Assembly

Figure 2



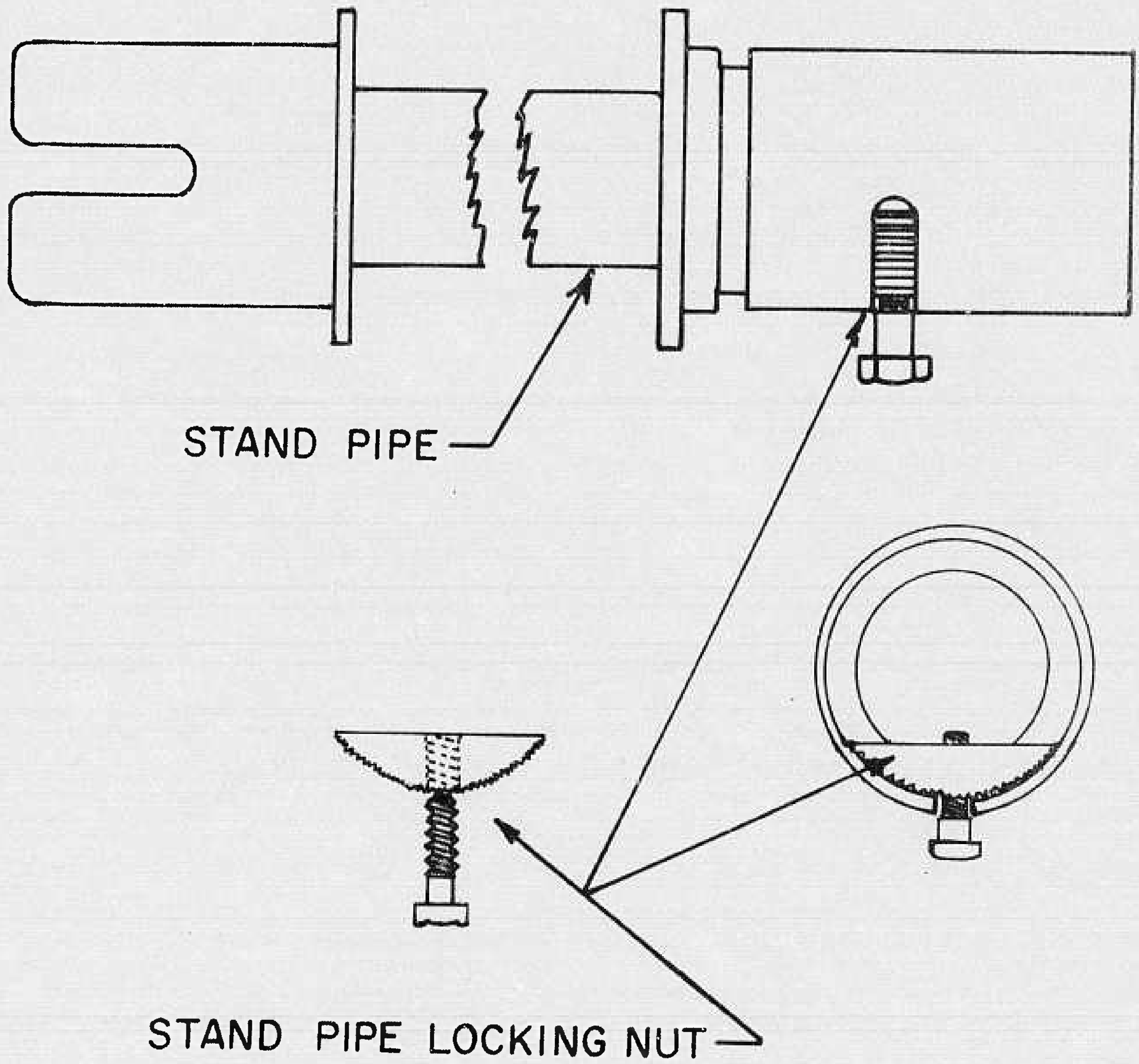
External Energy Transfer
Through Spinner-Cowl

Figure 3



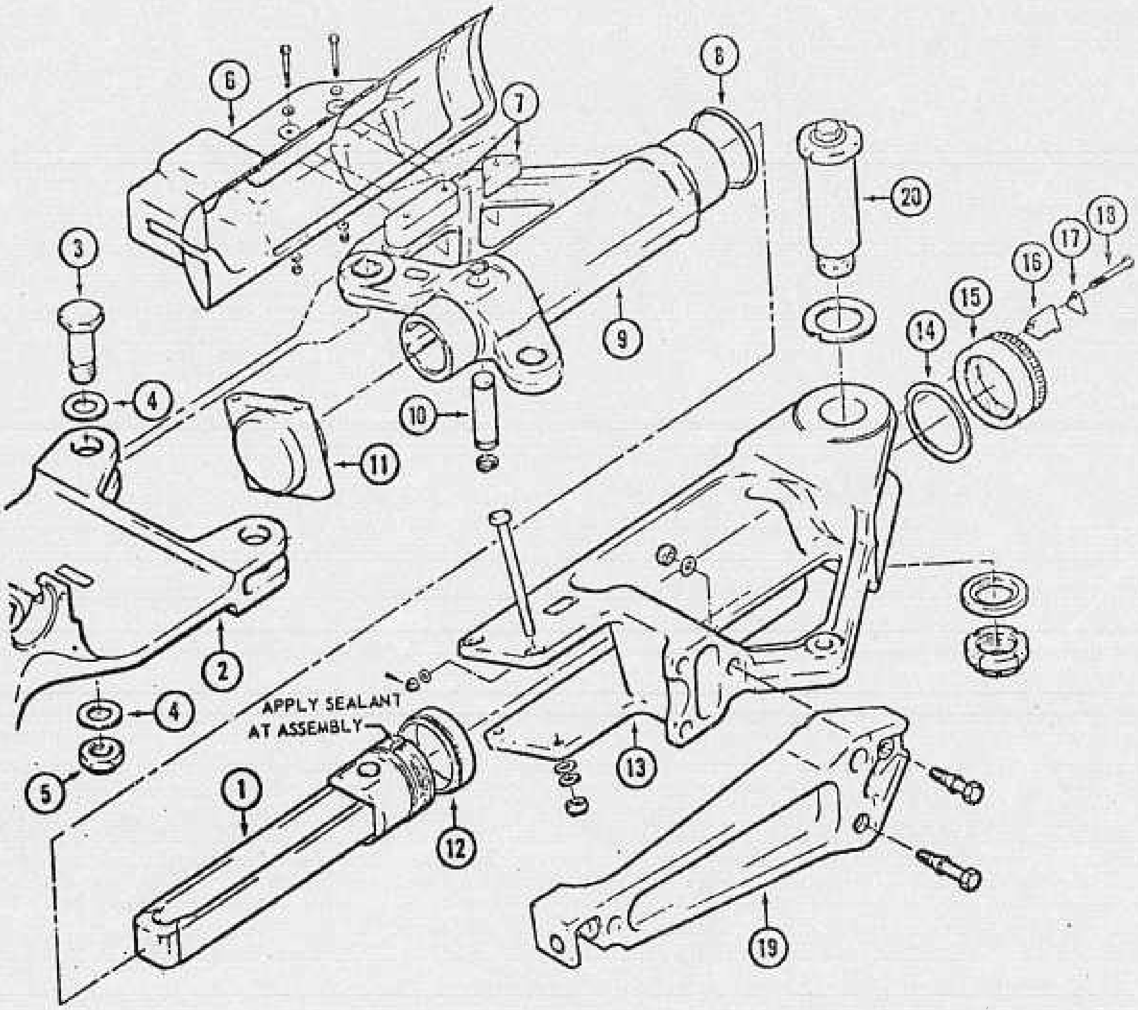
Internal Energy Transfer

Figure 4



Stand Pipe With Locking Nut

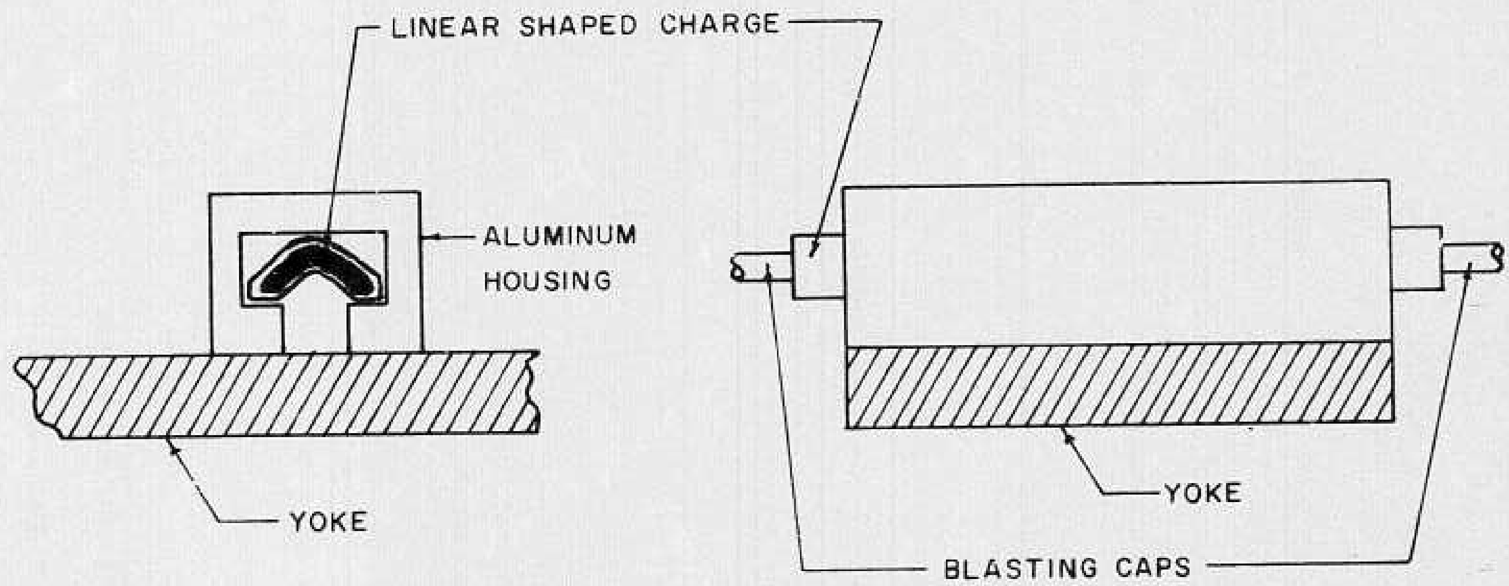
Figure 5



1. Strap Assembly
2. Yoke
3. Extension Bolt
4. Washers
5. Nut
6. Sand Deflector
7. Spacers
8. Radius Ring
9. Extension
10. Strap Pin
11. Inboard Bearing Housing
12. Dust Seal
13. Blade Grip
14. Washer
15. Grip Nut
16. Lock
17. Clamp
18. Bolt
19. Pitch Horn
20. Blade Bolt

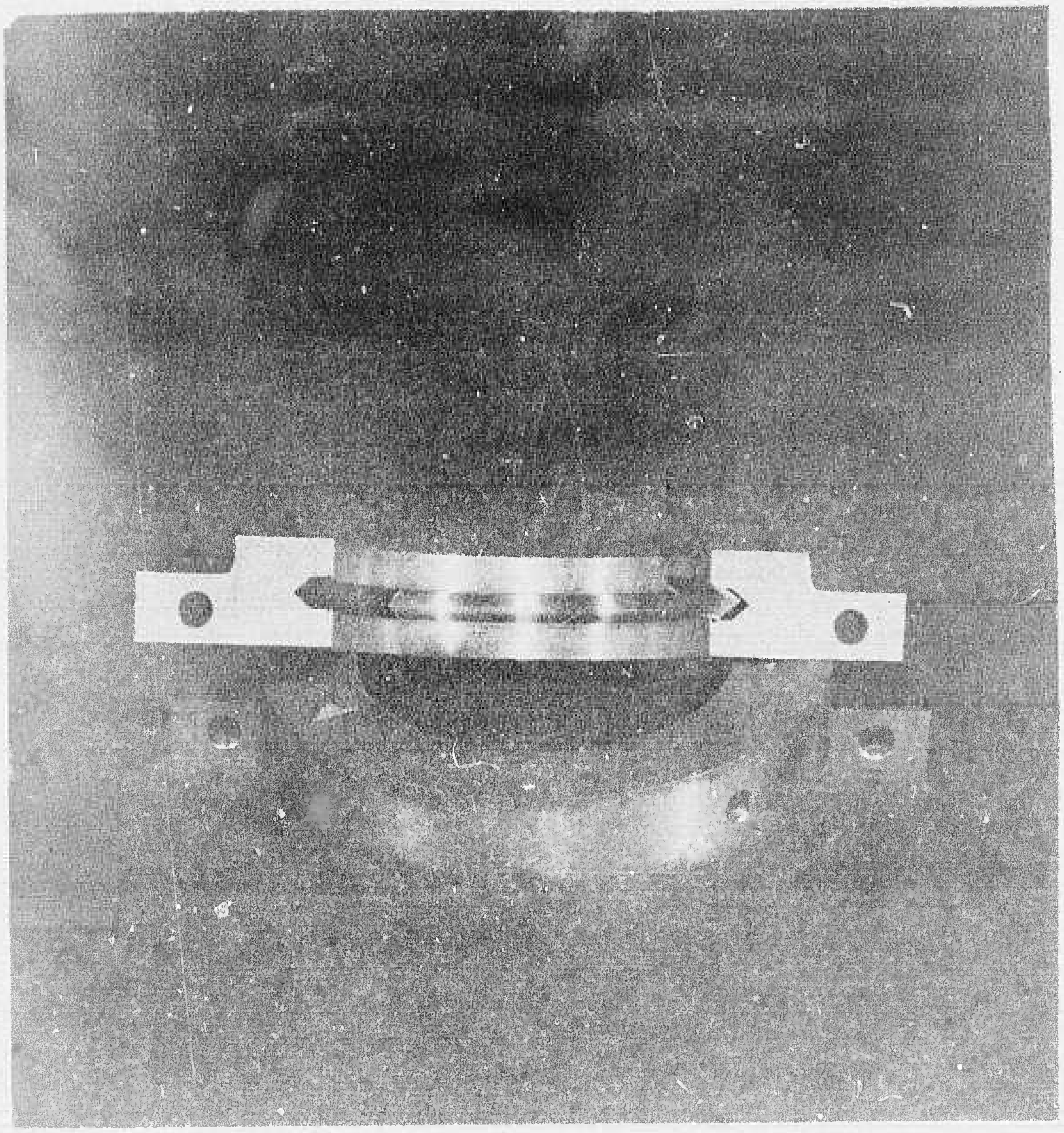
Main Rotor Hub

Figure 6



LSC Design for Severing Yoke

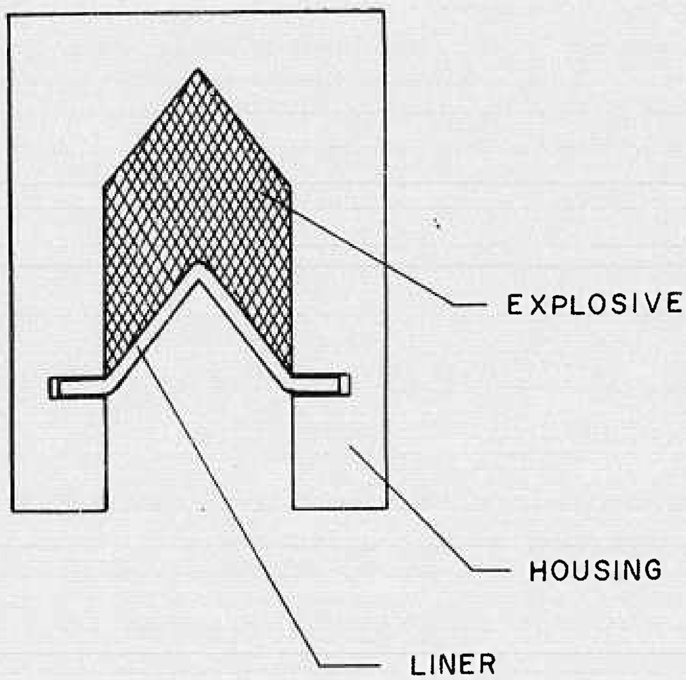
Figure 7



Shaped Charge for Rotor Mast

Figure 8

Figure 9



Yoke Charge Housing Cross Section

Figure 10

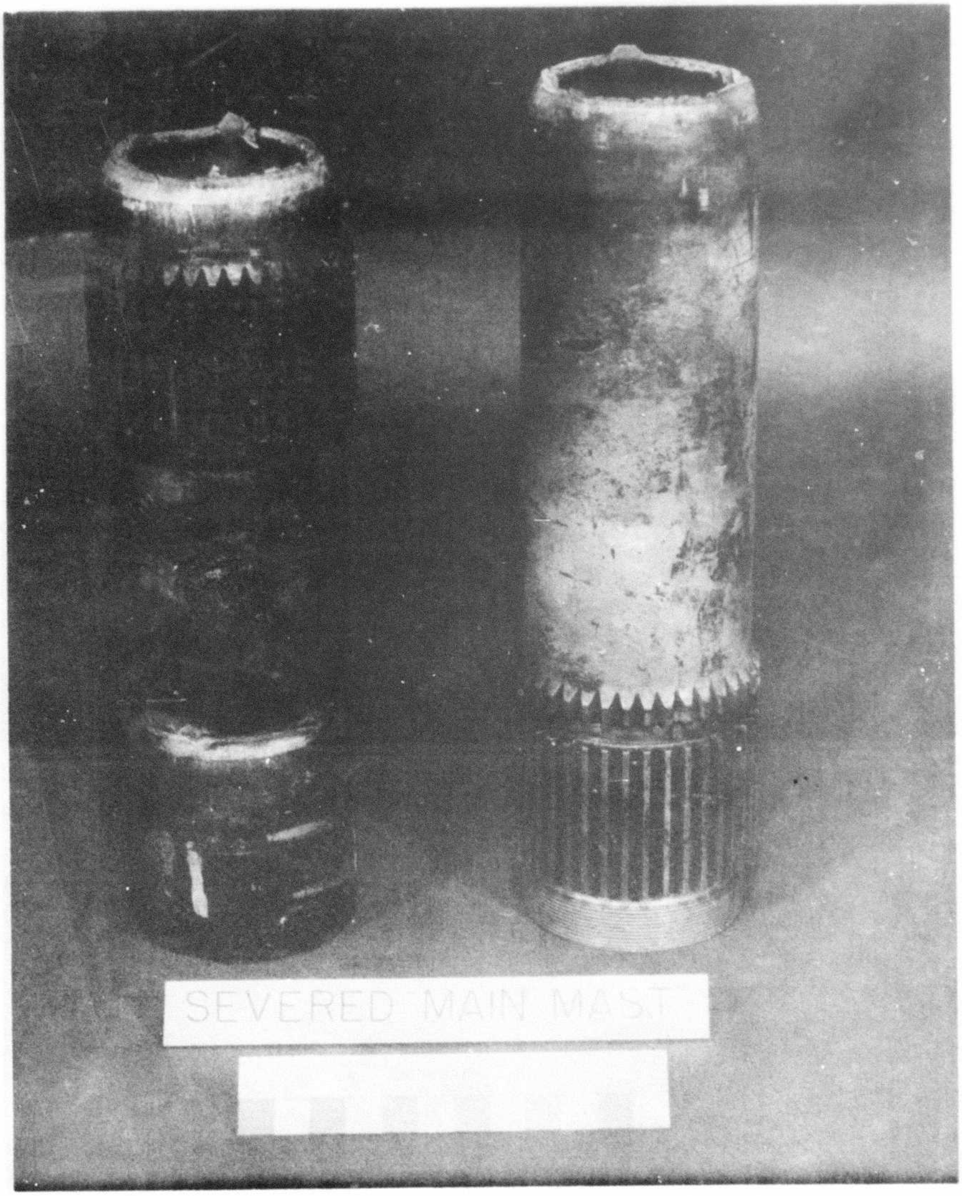
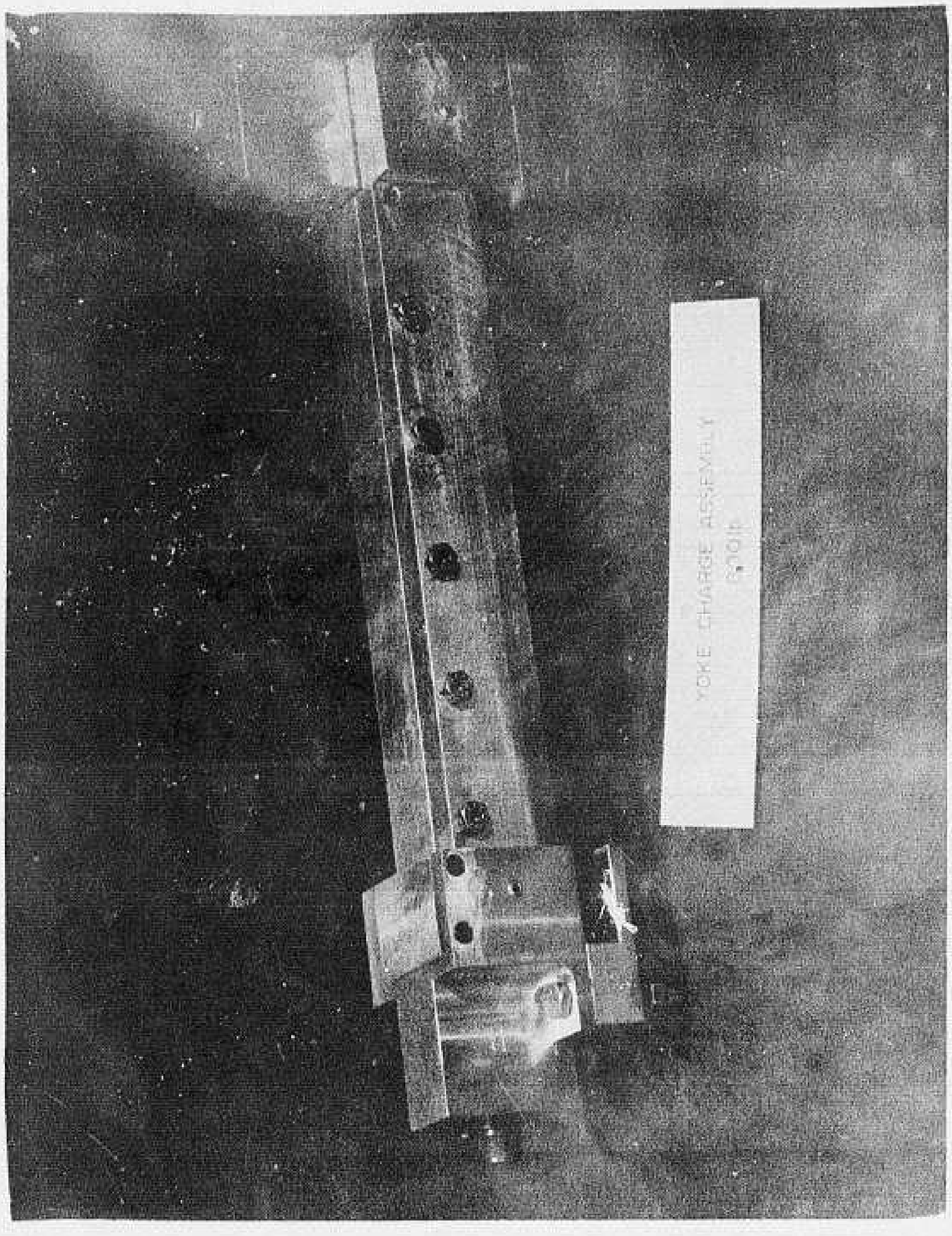
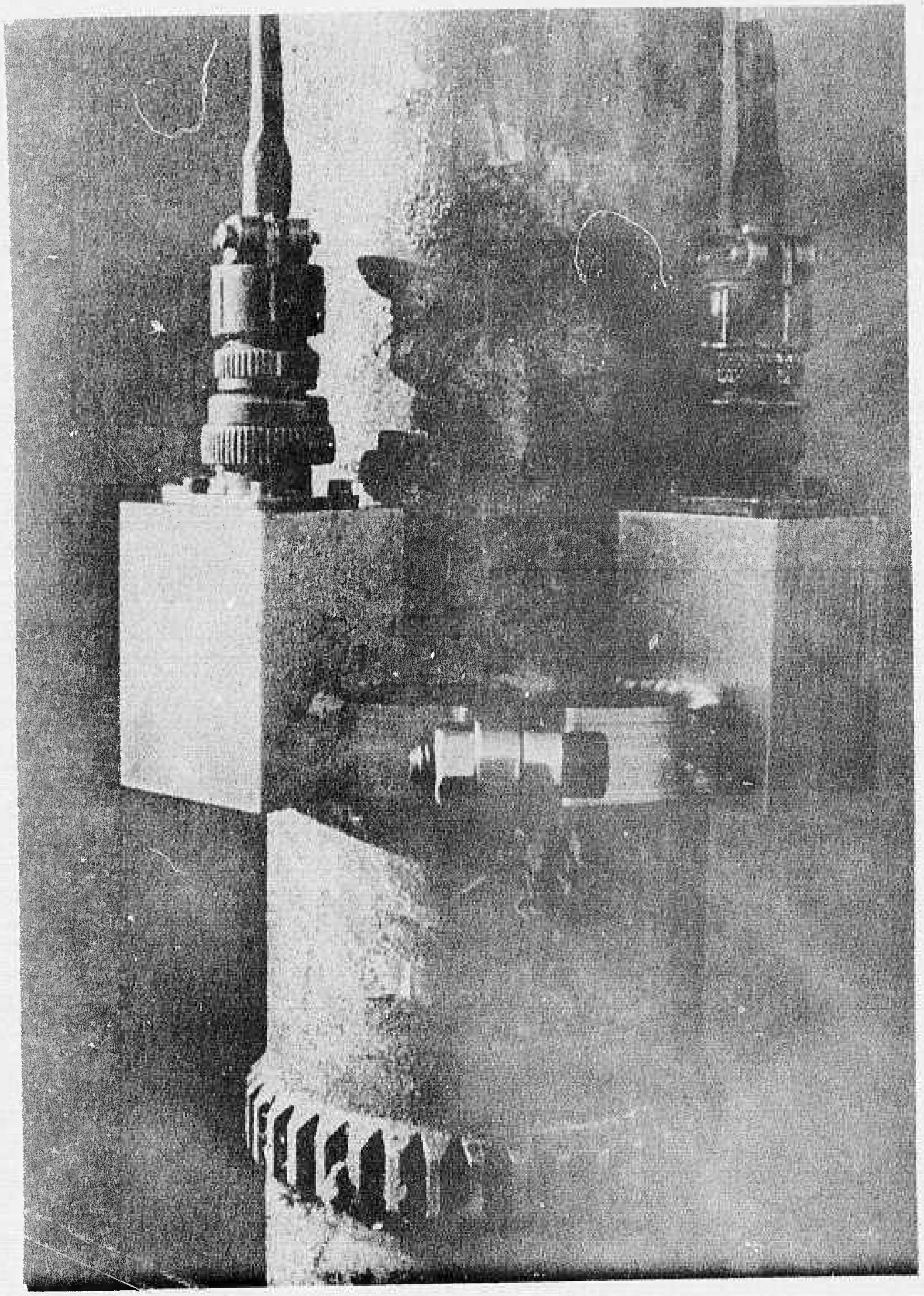


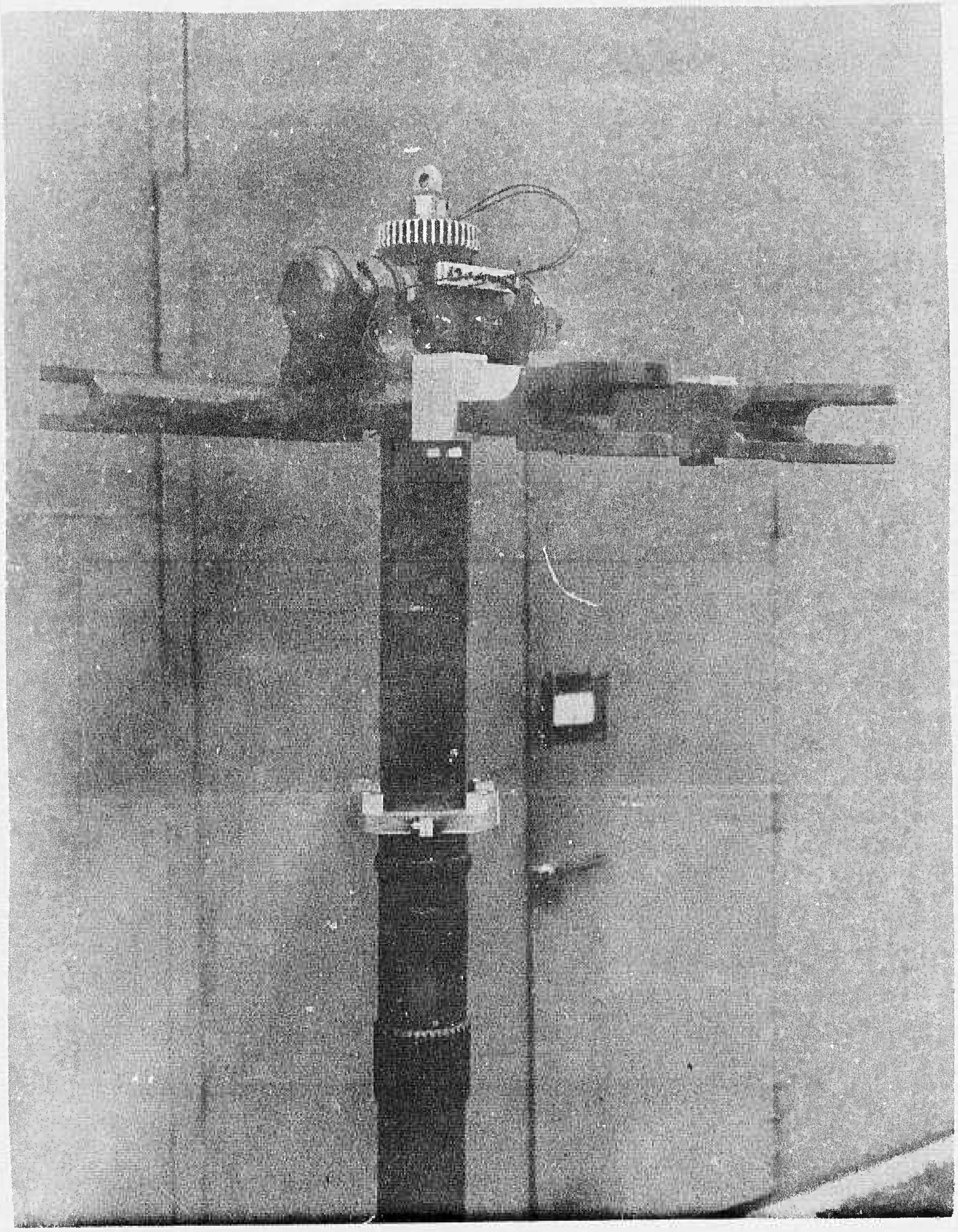
Figure 11


YOKE CHARGE ASSEMBLY



Charge Attached to Mast

Figure 13



Charges Installed on Mast and Yoke

Figure 14

CANOPY JETTISON ASSEMBLY

The AH-1 canopy consists of stretched acrylic sections supported by hollow aluminum extrusions which are 16 inches apart (less than a man's shoulder width) and pass down the length of the canopy (Figure 15). These members and an ADF antenna which is bolted between the two members above the pilot's seat (Figure 16) prevent egress through the canopy.

The major areas of investigation for the canopy jettison assembly were severance of the hollow extrusions (Figure 17), jettison of the canopy in a positive manner, and containment of any blast and fragmentation effects from the explosives used in severing the canopy.

CANOPY EXTRUSION SEVERANCE

Approximately 100 individual tests were performed on short sections of the canopy extrusions using linear shaped charges (LSC) (7 to 50 grains per foot) and detonating cord (det cord) (10 to 25 grains per foot) to optimize the cutting charge used to sever the extrusion. It was determined that 50 grains per foot of LSC could effectively cut the extrusion when modified per Figure 18. It was also determined that 15 grain per foot det cord could sever the canopy extrusion via an insert added to the hollow extrusion (Figure 19). In conjunction with the extrusion tests it was determined that 7 grain/ft LSC could sever the canopy acrylic and 10 grain/ft det cord could sever the antenna bolts. All of the above tests were conducted with lead sheathed HNS loaded LSC and det cord.

LINEAR SHAPED CHARGE AND DETONATING CORD MOUNTING AND CONTAINMENT

Approximately 75 tests have been conducted with various backup material and configurations of these materials to arrive at the optimum materials and configuration for holding the det cord and LSC in place and preventing any back blast and fragments from entering the cockpit. These tests show that the 7 grain LSC and 15 grain det cord can be held in place and be contained using a silicon rubber extrusion encased in 10 layers of 5.5 oz laminated fiberglas (Figure 20). This assembly can be bolted directly onto the canopy frame using rivnuts located two inches apart. The backup material was fabricated by the hand lay up method. The 10 layers of glass cloth were made to conform to a wooden model and each layer was bonded with polyester resin. Aluminum screen (Federal Stock No. RR-W-365) was bonded to the outside layer of glass cloth for additional strength. The wooden molds for the lay up where formed directly from the canopy frame. The optimum material for containing the 50 grain LSC has not been determined.

CANOPY JETTISON

Four methods to jettison the canopy were initially investigated with the following three methods showing the most promise:

1. Sever the canopy approximately in half longitudinally, leaving the vertical structural members attached to either side of the fuselage to act as hinges so both halves could "clamshell" open.

2. Sever the canopy as above except that the two halves would not remain attached to the fuselage but would be jettisoned away from the helicopter.

3. Completely sever the canopy in one piece and jettison it up and toward the rear of the helicopter.

The fourth method was to sever the canopy in one piece and remove it in a forward direction by the use of rockets. In the first three methods two M1A3 canopy removers were selected to open and/or jettison the canopy. The M1A3 remover was selected because it was off-the-shelf and available.

CANOPY JETTISON ASSEMBLY TESTS

The first static test on a full scale engineering model of the canopy jettison assembly using the clamshell approach (No. 1) was conducted in June 1972 at NSWC/DL. Figure 21 shows the location of the LSC and the X-814 electric blasting caps that were used to initiate the LSC. The technique of attaching the seven and 50 grain LSC together is shown in Figure 22. Figure 23 shows the technique of attaching the M1A3 removers to the vertical members of the canopy. The test was a limited success because the blasting caps failed to fire a portion of the LSC train.

A second static test was conducted in July 1972 at NSWC/DL, again to demonstrate the No. 1 "clamshell" approach. The same sizes of LSC were used and were positioned as in the first test. The canopy sections were successfully severed but the M1A3 canopy removers completely jettisoned the canopy sections instead of leaving them attached as planned. Analysis of the test data indicated that there was not sufficient strength between the vertical structural member and fuselage to permit this junction to act as a hinge. Since the canopy cleared the fuselage satisfactorily within 200 milliseconds it was decided to conduct a dynamic test of this jettison concept in which the canopy halves would be removed from the fuselage.

A dynamic test was conducted at a speed of 174 knots at NATF Lakehurst in August 1972. The helicopter was mounted in the most critical attitude with respect to aerodynamic loading (25° nose left and 5° nose down). The canopy was cleanly severed and all sections were clear of the crewmen's egress path within 225 milliseconds. Photographic coverage of the test indicated that due to aerodynamic loading the canopy structure failed prematurely and the canopy broke into several pieces, one of which could have struck the gunner's legs.

In the above three tests the LSC and the removers were positioned as shown in Figures 21 and 23, respectively.

A static test was conducted in March 1973 at NSWC/DL of the "up and to the rear" concept of canopy jettison. An uncut canopy was mounted on a wooden mock-up of the AH-1 fuselage section (Figure 24). This test was not considered a success because one canopy remover broke loose from its wooden base during the canopy jettison sequence. There also was a 15 to 20 knot side wind, gusting during the test sequence, resulting in the canopy going to one side and not up and over as planned.

A second static test of the "up and to the rear" concept was conducted. The test set-up was the same as above but with a strengthened mount for the removers. The canopy was jettisoned up and approximately 15 feet to the rear.

In April 1973 a third static test of the "up and to the rear" concept of canopy jettison was conducted. To be as realistic as possible, saw cuts were made on the canopy and surrounding canopy structure in the locations where the LSC would be used. The test was a partial success in that the canopy did not travel as far up and to the rear as predicted. Examination of the test films showed that the cut canopy started to collapse upon canopy remover firing. It appeared this collapsing was due to the method of attaching the removers to the canopy.

No additional tests were conducted on the "up and to the rear" concept due to funding limitations. All effort was concentrated on the clamshell concept and a second dynamic test of the canopy jettison assembly was conducted at NATF Lakehurst on 27 July 1973. The test was conducted at a speed of 150 kts and the test vehicle was oriented 5° nose down and 25° left yaw. The canopy glass was cut with seven grains per foot LSC, and the canopy structure was severed with 50 grains per foot LSC (Figure 26). Six X-814 blasting caps were used to initiate the LSC. The LSC was attached to the canopy with rivnuts and confined with a silicon rubber extrusion underneath a laminated fiberglas backup (Figure 20). Two M1A3 aircraft canopy removers were used to jettison the canopy after it was severed by the LSC. The base of the M1A3's were attached to an NSWC/DL designed mount located at helicopter station 105 above and clear of the pilot's feet (Figure 25). The head of each remover was attached to the vertical structural member of the canopy frame. A visual examination of the cockpit area and the canopy jettison assembly components after the test indicated that all components had functioned as designed, except that a portion of the seven grain LSC failed to sustain detonation along its full length.

After examining the test films it was determined that the poor performance in this test was due to one longitudinal canopy structural member not being severed. This member was located just in front of the ADF antenna on the left side looking forward, and was to have been severed by a section of 50 grain LSC (Figure 26). The piece of 50 grain LSC could have been initiated from either end by the seven grain LSC which was used to cut the canopy glass. However, one piece of seven grain LSC was damaged when an adjacent electric blasting cap (EBC) fired through a metal buffer plate that had been placed around the EBC to prevent this occurrence. The other section of seven grain LSC apparently was damaged during installation of the LSC or the booster between the 7 and 50 grain LSC. These breaks therefore prevented initiation of the 50 grain LSC.

Because of the problems that had been encountered in using different charge weights of LSC a technique was developed in which 15 grain detonating cord was used to sever both the structural members and the acrylic. In this technique a section of extrusion was removed at a point where the canopy was to be severed, and an insert (Figure 19) was then positioned and bolted in place. An aluminum insert was used in initial tests but this was changed to a titanium insert in order to maintain equivalent canopy strength. In this technique the antenna was removed by inserting the det cord between the antenna and the structural members it was bolted to. Upon initiation of the det cord the antenna was torn loose from the bolts. This technique reduced the amount of handling that the explosives required thus reducing the possibility of cracking the explosive.

In October 1973 a static canopy jettison test of the clamshell concept was conducted in which the structural inserts and 15 grain/ft det cord were used as the severing element (see Figure 27 for orientation of det cord and detonation points). Figure 28 shows the cross section of the explosive tee's which were designed to eliminate 90° bends of the det cord. The concept of attaching the M1A3 canopy removers to the base of the pilot's gunsight was also evaluated (per BHC Dwg. SK104). See Figures 29 and 30 for location of canopy removers. It was necessary to reinforce the canopy frame in order to transfer the remover loads to the canopy. The transverse canted frame was reinforced on the inside with a steel doubler of angle cross section. The doubler extended from the remover fitting at the lower end to the intersection of the transverse and longitudinal frame members at the upper end. The upper end of the doubler was welded to a "T" fitting bolted to the longitudinal member. The longitudinal members were reinforced with steel doublers of channel cross section bolted to the outside of the longitudinals. These doublers extended 20 inches fore and aft of the intersection of the transverse and longitudinal frame members. All the components functioned as designed resulting in a complete severance and jettison of the canopy. The two halves of the canopy were reasonably intact after being jettisoned.

In December 1973 a dynamic canopy jettison test was conducted at NATF Lakehurst in which 15 grain det cord was used as the cutting element. Canopy jettison assembly components were positioned the same as in the static test performed at NSWC/DL in October 1973. The test was conducted at a speed of 150 kts and the test vehicle was oriented 5° nose down and 25° left yaw. A visual examination of the cockpit area and the canopy jettison assembly components indicated that all components functioned as designed with the exception that the titanium insert in the gunner's right vertical structural member did not fracture. Post-test examination revealed that the det cord definitely detonated inside the insert and that the insert had been fabricated in accordance with the drawing. A metallurgical analysis of the insert was performed by NADC Warminster in an attempt to determine why it did not fracture. Even with the insert not fracturing the canopy was opened and jettisoned and would have provided a clear escape path for the crewmen. The det cord was successfully initiated by two FMU-119A electric detonators which were designed by NSWC/DL. The noise level of the canopy jettison system was recorded during the last two dynamic tests and the maximum level recorded was 161 db.

Up to this point in the design of the canopy jettison assembly the weights of the components are as follows:

M1A3 canopy removers (2 required)	4.2 lbs
15 grain/ft det cord (26 ft required)	1.0 lb
Backup material (26 ft required)	11.0 lbs
Mounting hardware for removers	2.25 lbs
Detonator holders (2 required)	0.70 lb
Titanium inserts	2.25 lbs
Total system weight	21.40 lbs

Preliminary engineering design has been started on a cable cutter to sever the cables to the head sets and ADF antenna that have to be removed before the canopy can be jettisoned. The cable cutter blade will be actuated by 15 grain/ft det cord so it can be part of the canopy severing explosive train (Figure 31).

In June 1973 Frankford Arsenal, Philadelphia, Pennsylvania was funded to redesign the canopy removers within the following parameters:

1. Provisions for dual electrical cartridges.

2. Supply base plates similar to M1A3, but no top plate - NSWC/DL will provide.

3. Maximum weight each - 1.75 pounds.

4. Maximum jettisoned canopy weight - 109 pounds.

5. First movement pressure as low as possible.

6. Outside diameter cannot exceed M1A3 diameter (prefer smaller O.D.).

7. Include provision for sealing gases in locked shut condition.

8. Assume approximately 23 inch stroke - time .180 second from initiation.

9. Desire approximately 3,000 lb maximum thrust.

10. Flatten thrust-time curve as compared with M1A3.

11. Manifolding of cartridge output.

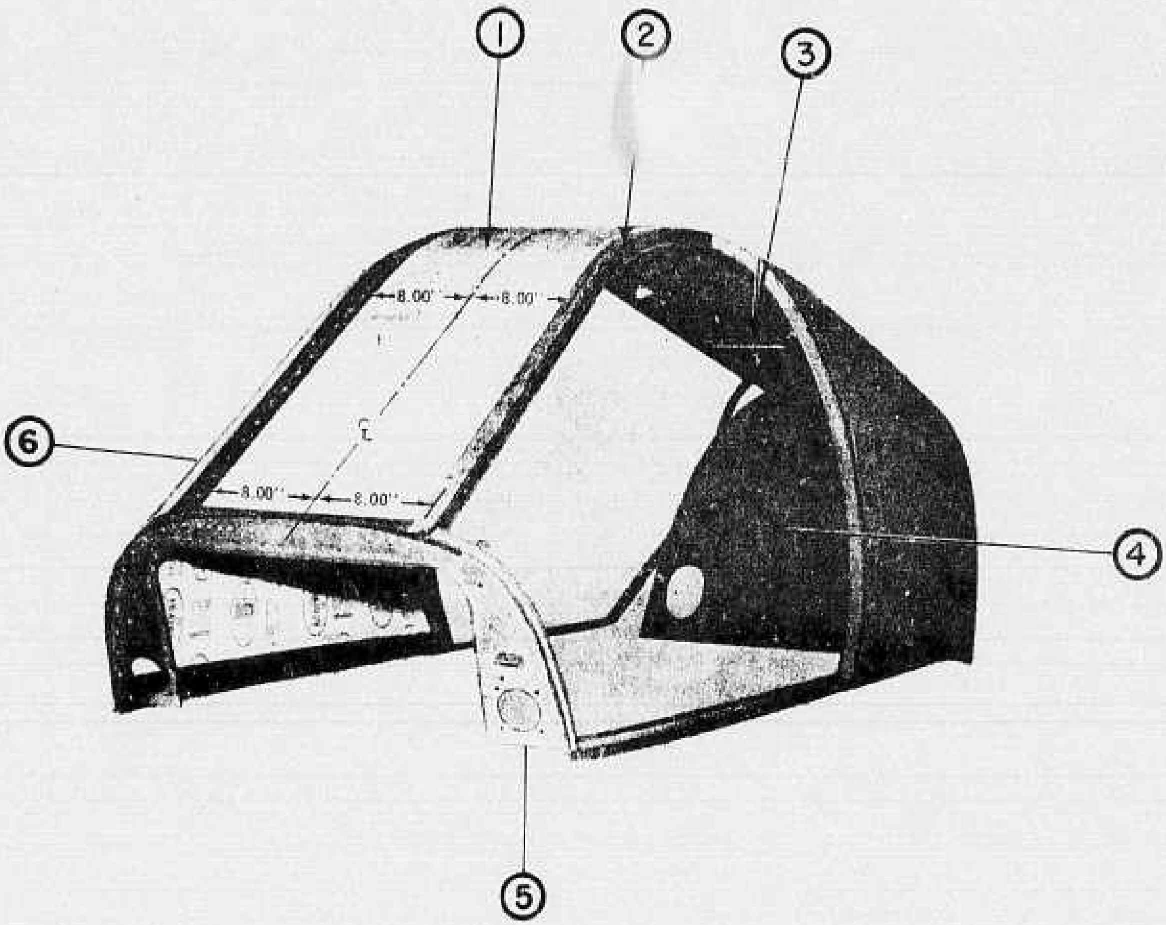
Frankford Arsenal has done preliminary design work on a remover to satisfy the above requirements but no hardware has been manufactured or tested.

RECOMMENDATIONS

To insure a reliable canopy removal assembly the following recommendations should be considered:

1. The hinges on both the pilot's and gunner's doors should be strengthened to hold the doors to the canopy frame during canopy jettison.

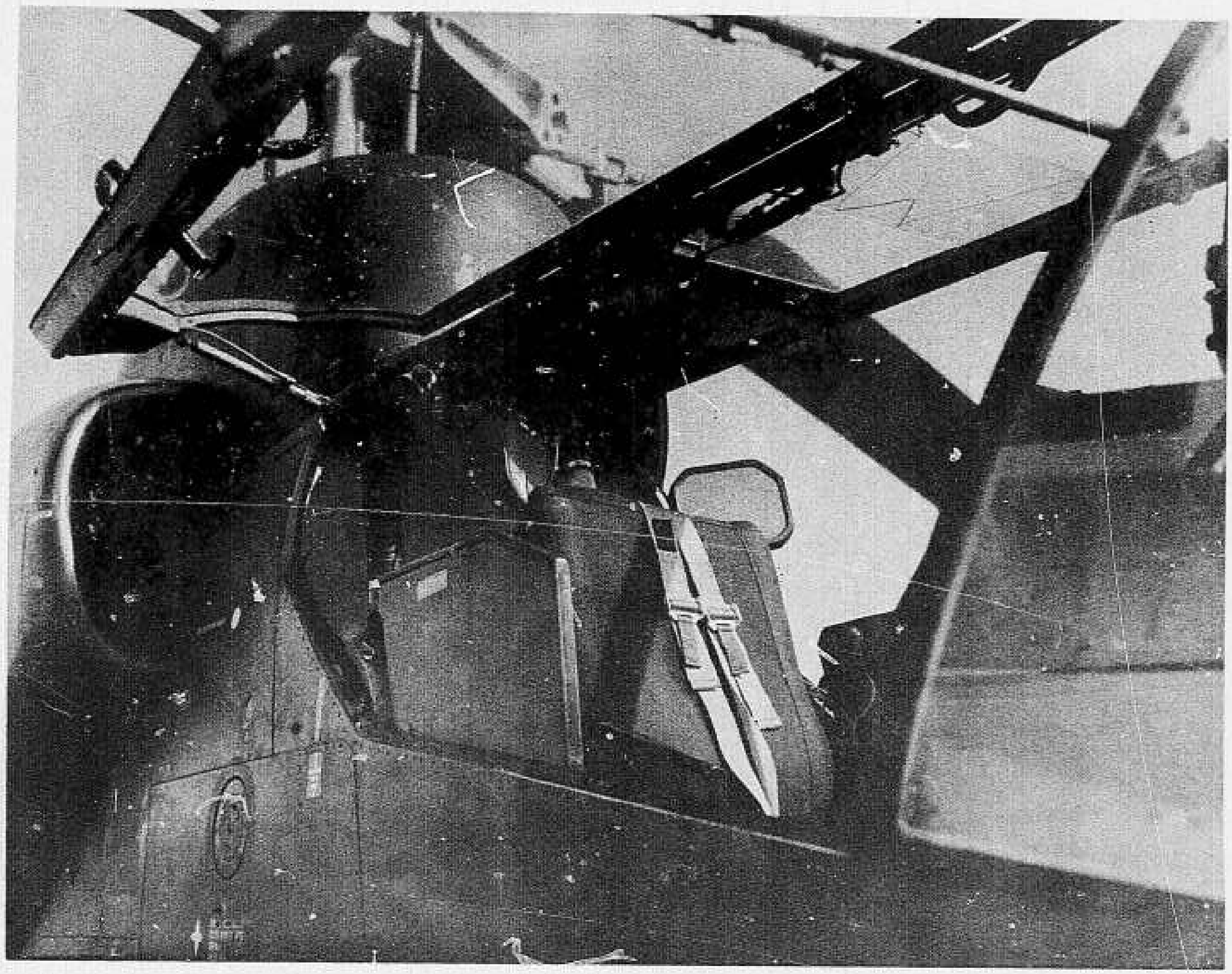
2. The vertical and longitudinal extrusions of the canopy should be strengthened to withstand aerodynamic loading and remover loading during canopy jettison.



1. Center Window
2. Left Canopy Frame
3. Cross Member (4 Places)
4. Aft Bulkhead (Reference)
5. Forward Bulkhead (Reference)
6. Right Canopy Frame

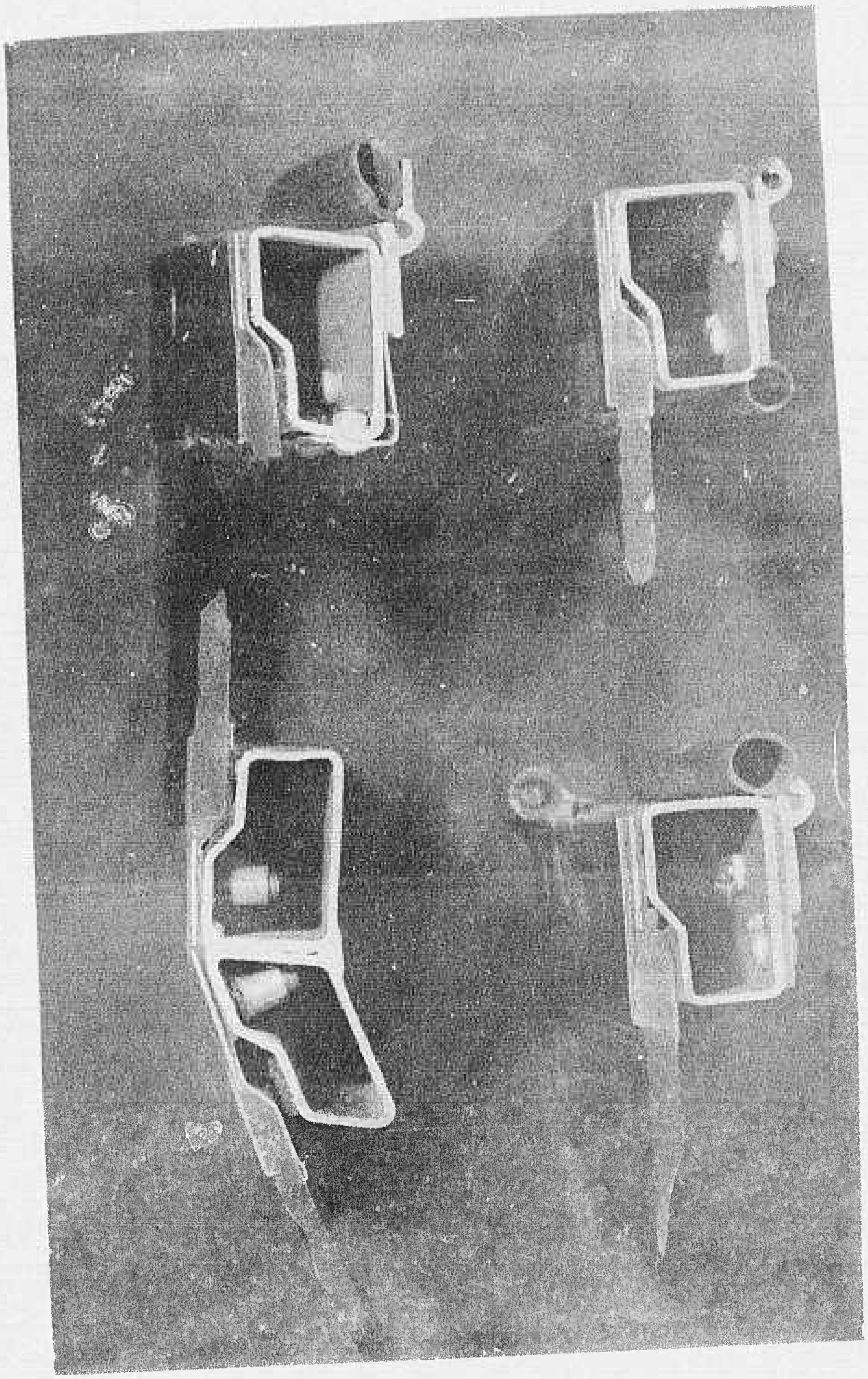
AH-1 Canopy

Figure 15



ADF Antenna

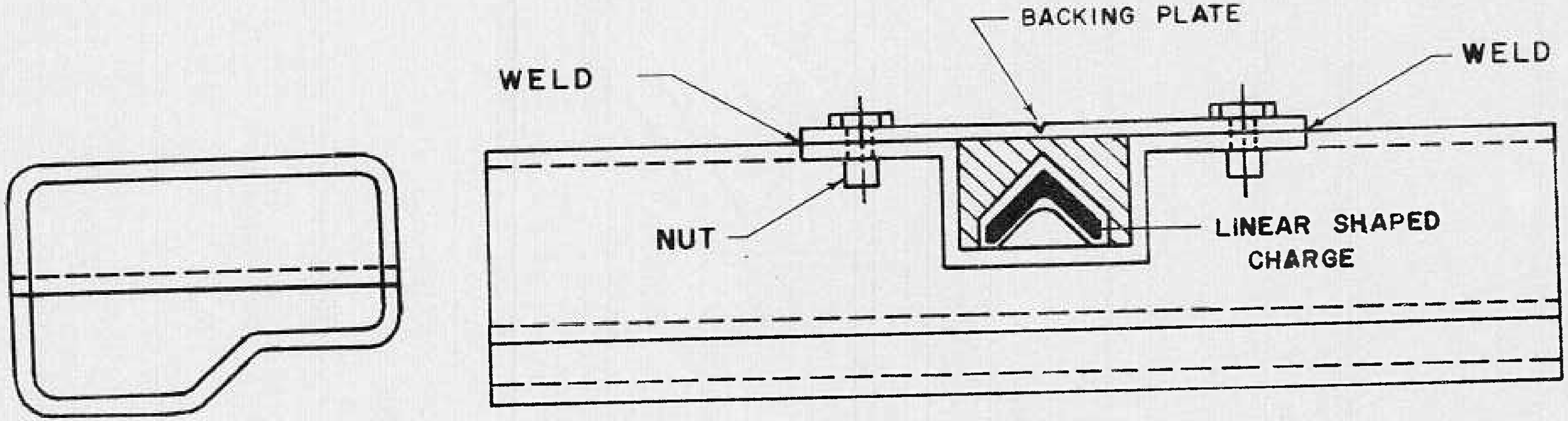
Figure 16



Typical Cross Sections
of Canopy Frame Members

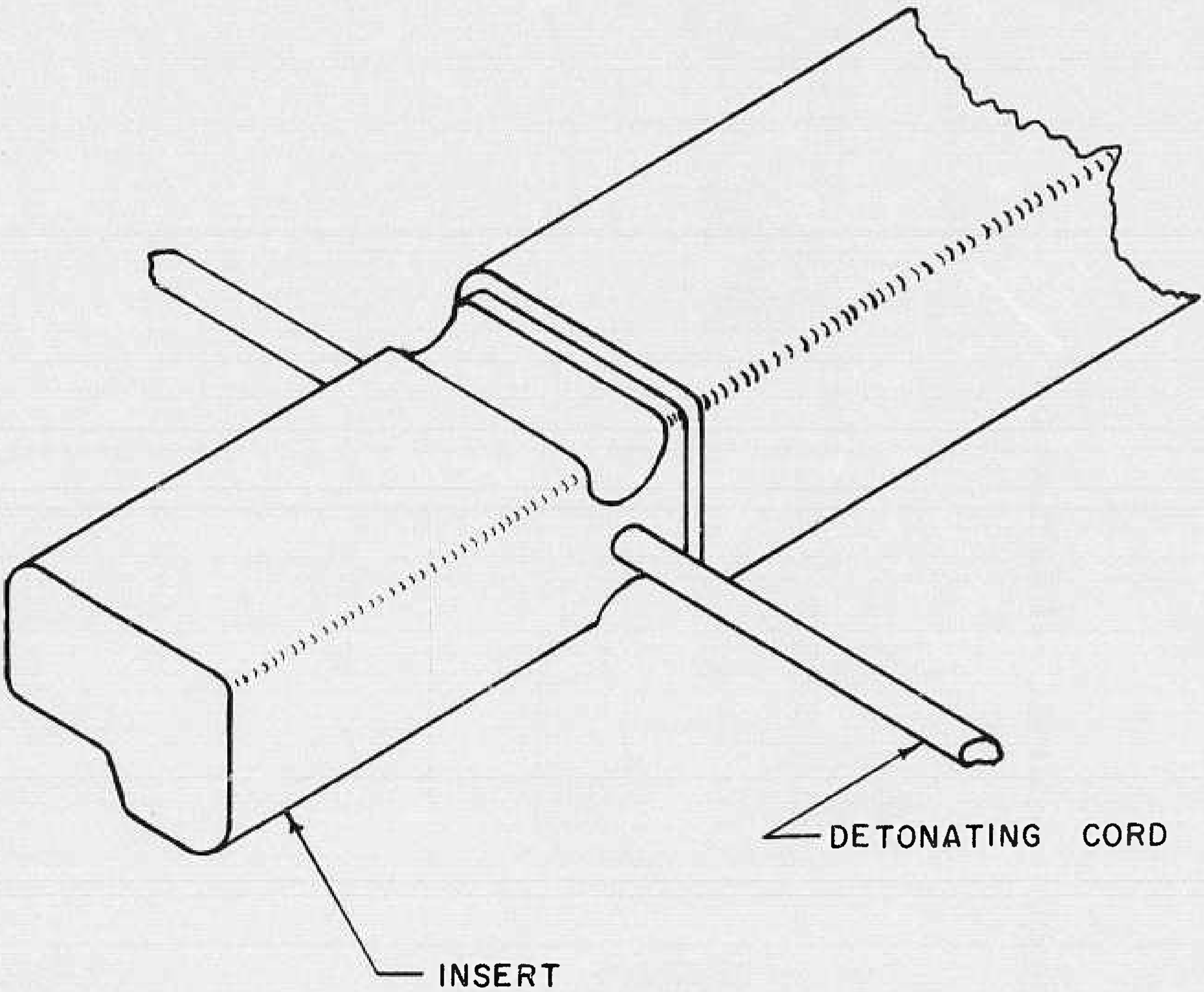
Figure 17

CANOPY CHANNEL MODIFICATION



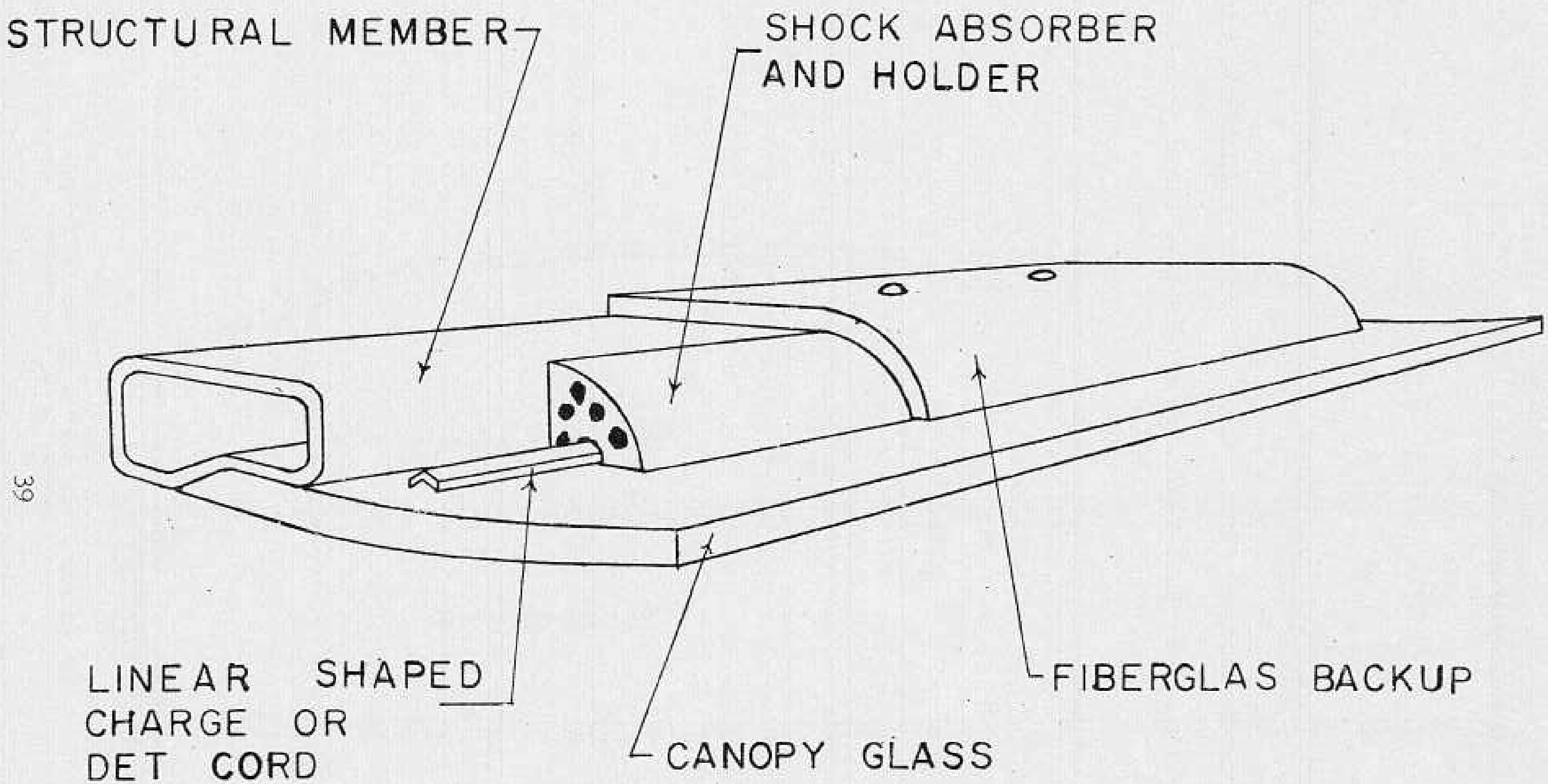
Structural Member Modified for LSC Severing

Figure 15



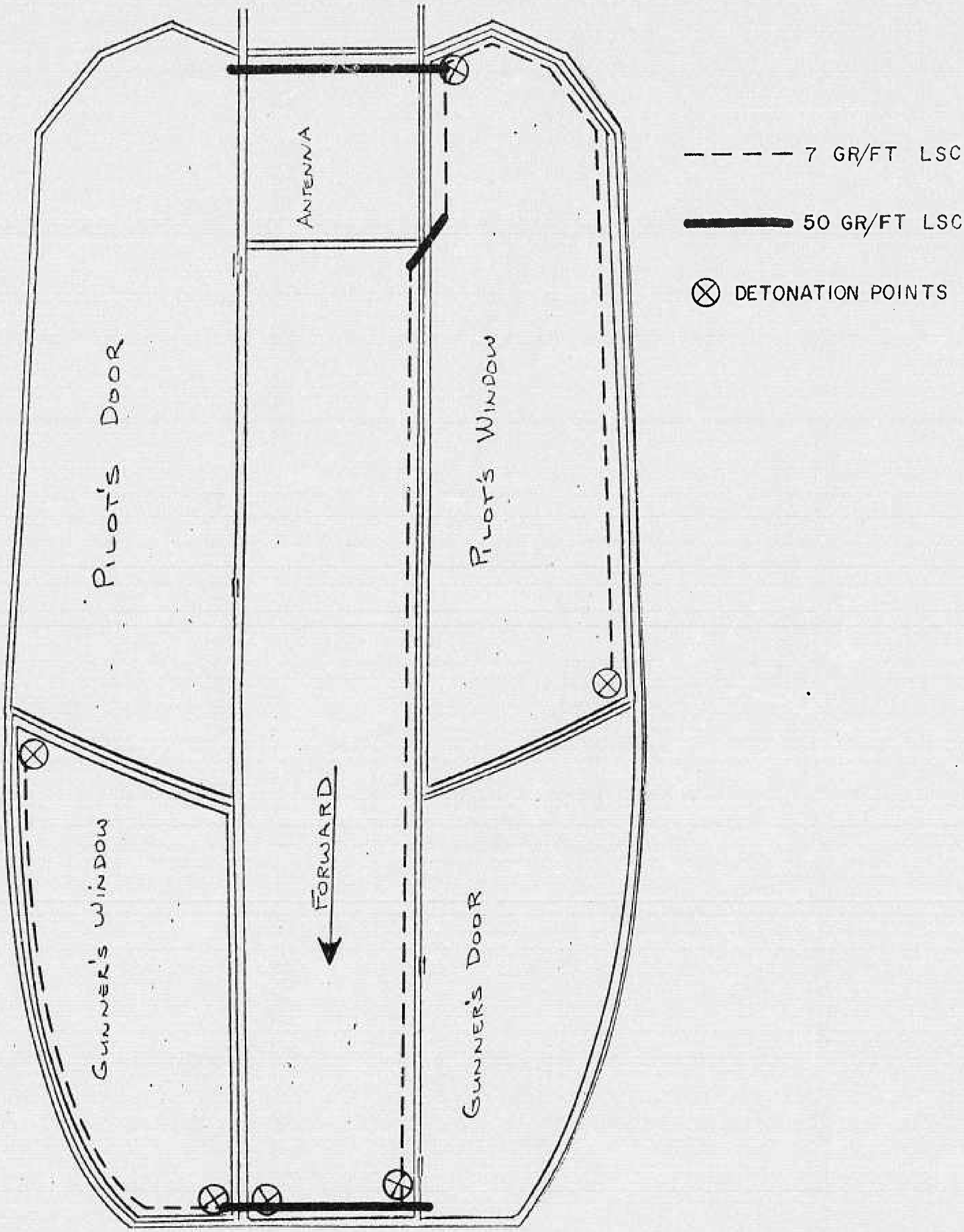
Insert for Detonating Cord

Figure 19



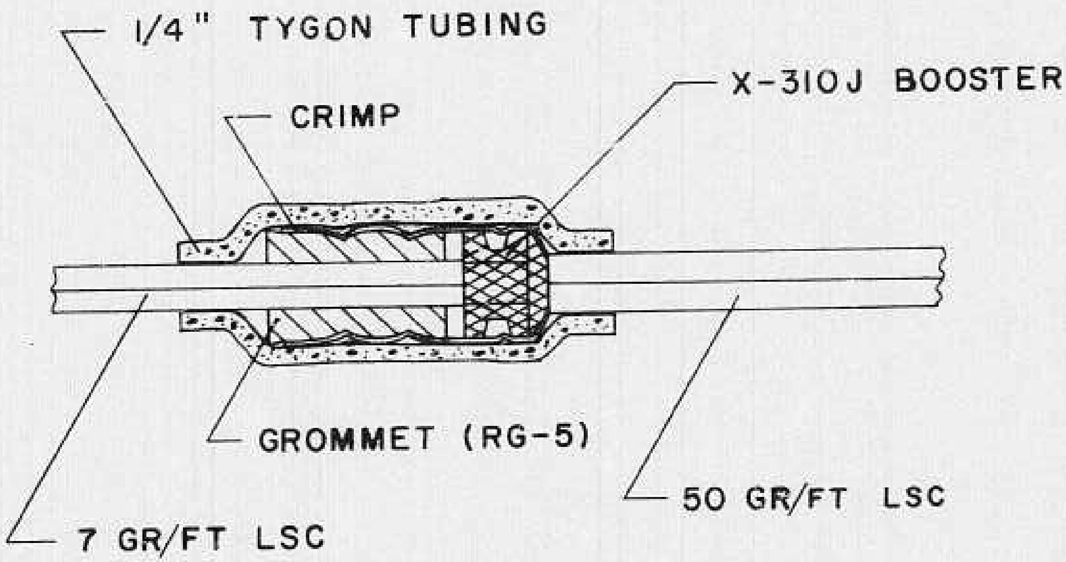
Cross Section of Backup Assembly

Figure 20



Set Up for First Static Canopy Test
Using LSC

Figure 21



Attachment of 7 and 50 grain/ft LSC

Figure 22

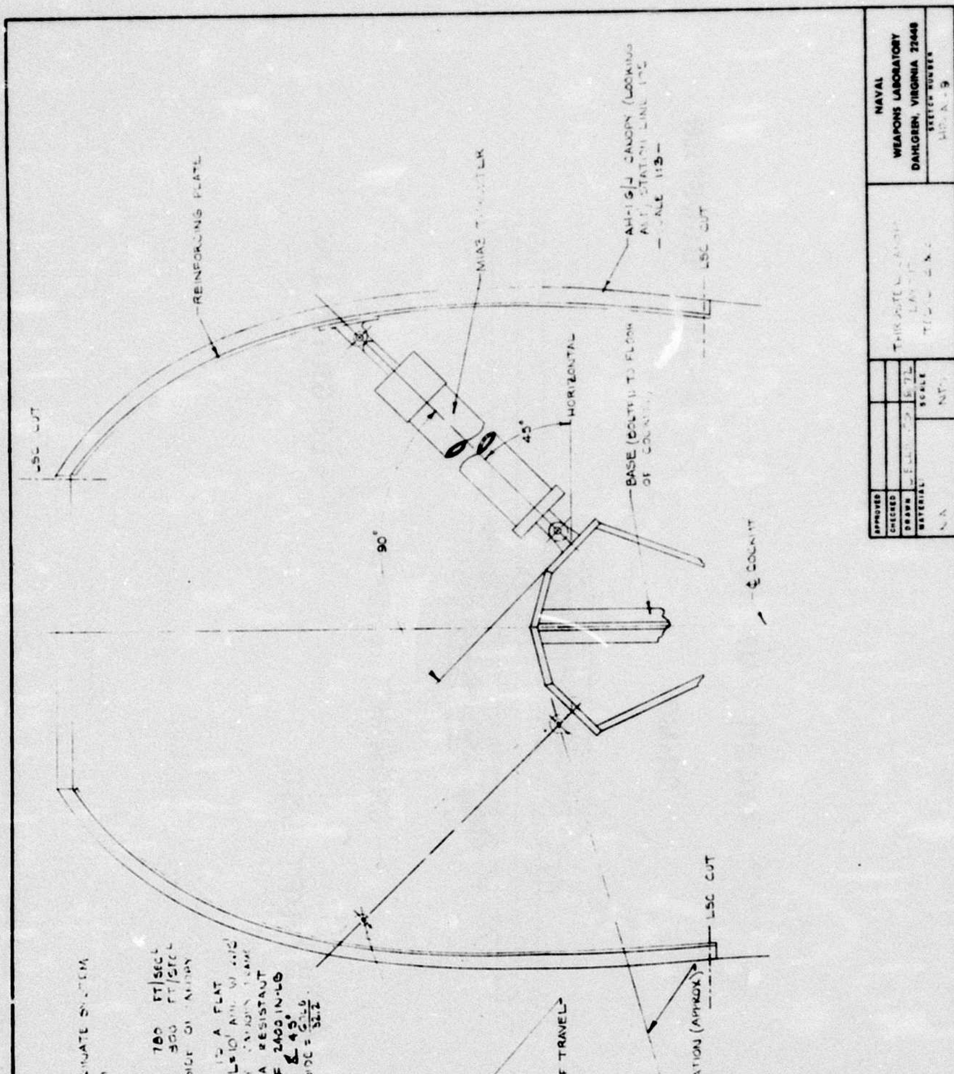
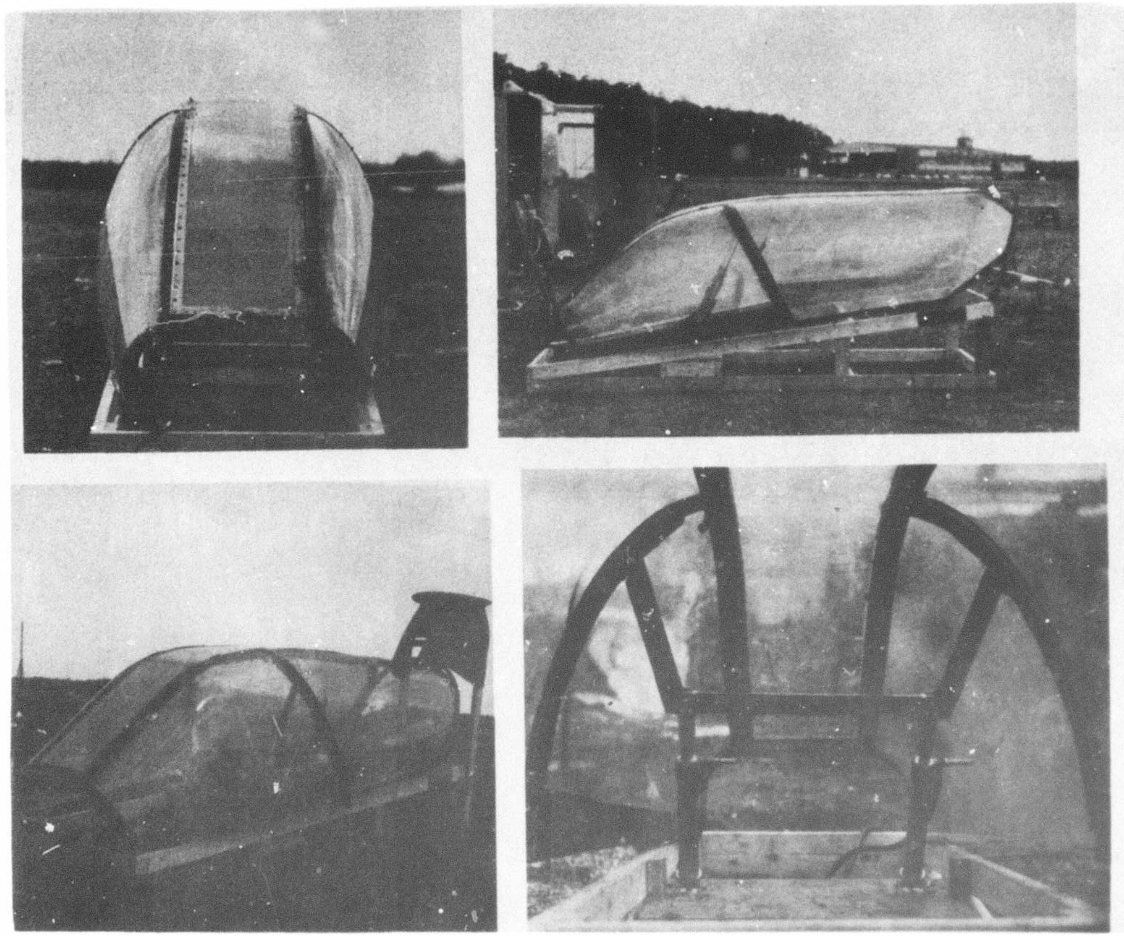

NAVAL
WEAPONS LABORATORY
DAHLGREN, VIRGINIA 22448
REINFORCING PLATE
LSC CUT
LSC CUT
LSC CUT
HORIZONTAL
45°
90°
BASE (BOLTED TO FLOOR OF COCKPIT)
℄ COCKPIT
DIRECTION OF TRAVEL
FINAL ORIENTATION (APPROX)
NOTES:
150 SLUGS

Figure 23



Pretest Set Up of Up and to the Rear Concept

Figure 24

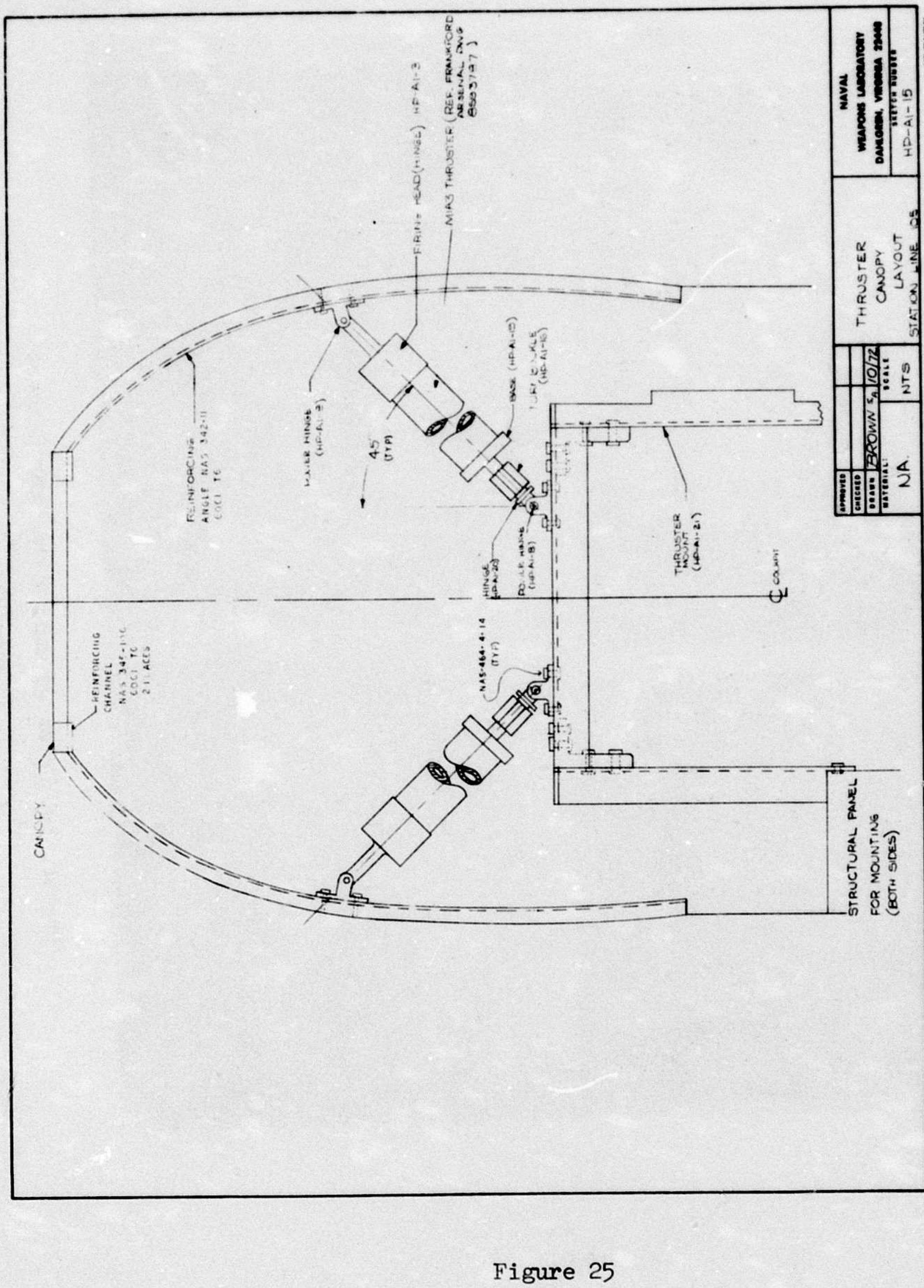
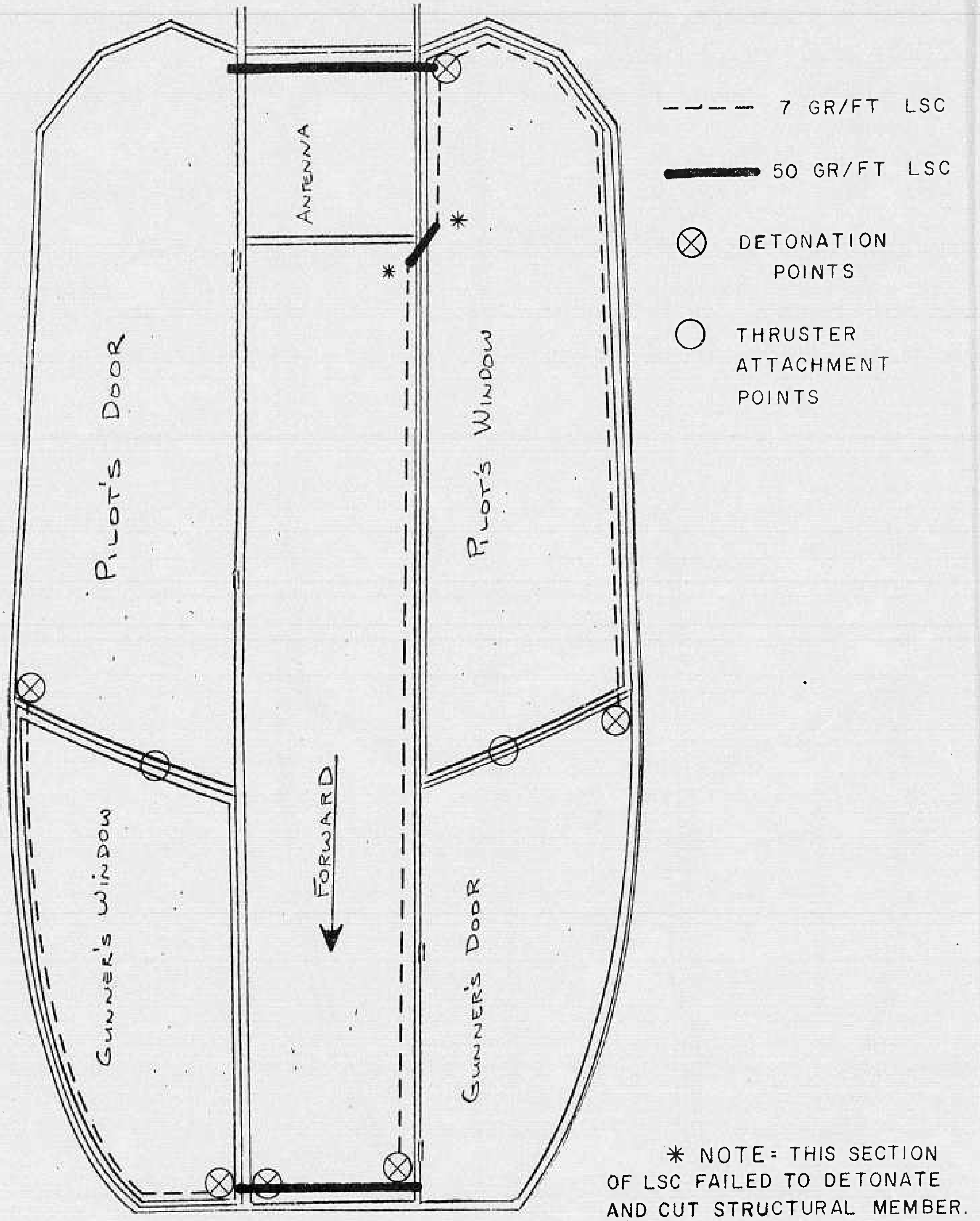
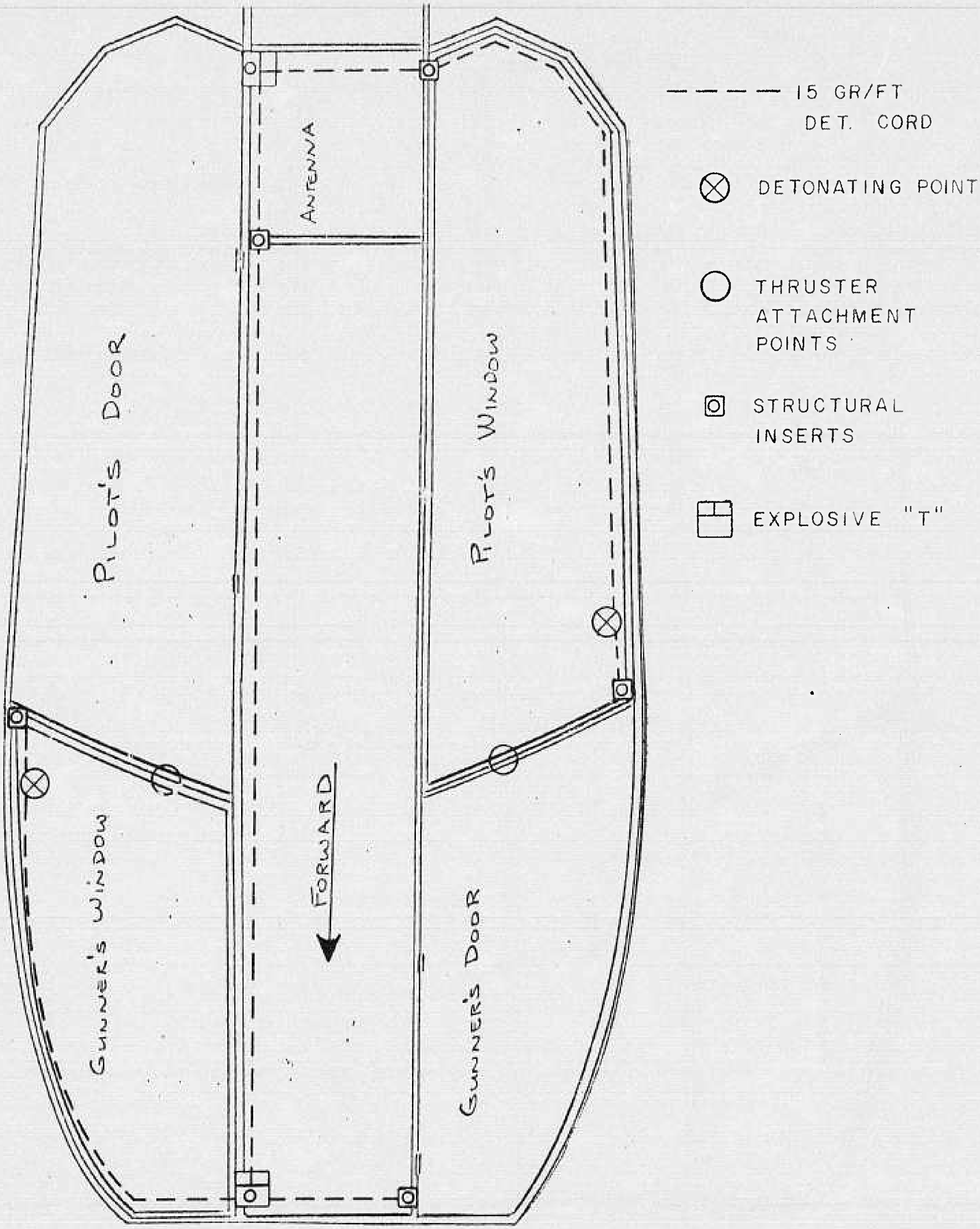

CANOPY
STRUCTURAL PANEL FOR MOUNTING (BOTH SIDES)
THRUSTER CANOPY LAYOUT STATION LINE 105
NAVAL WEAPONS LABORATORY DAHLGREN, VIRGINIA 22448
HP-A1-15
BROWN
10/72
NTS
N.A.

Figure 25



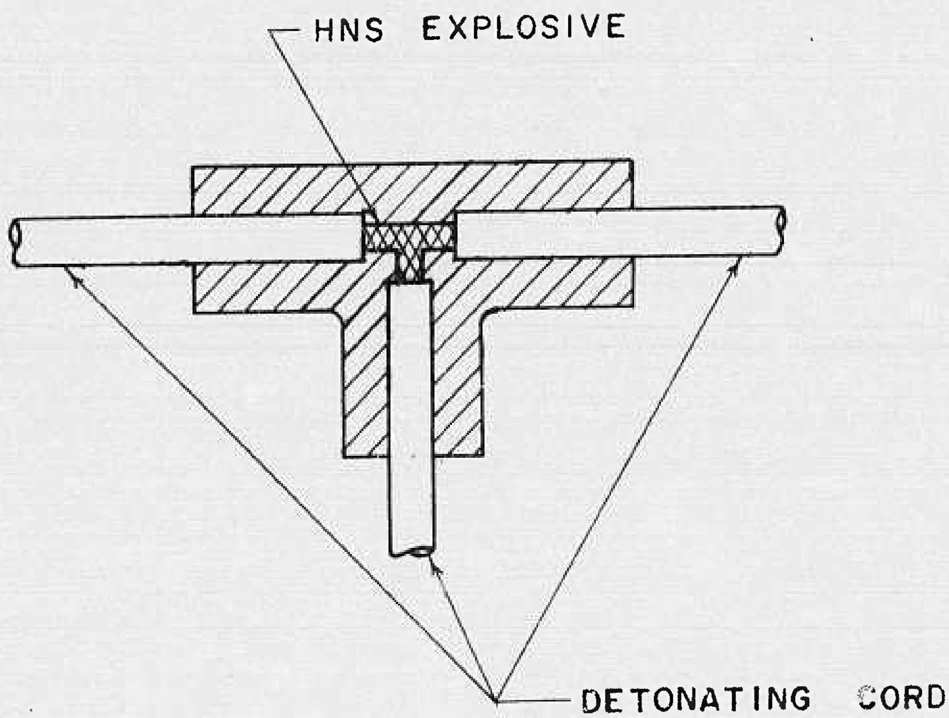
Set Up for Second Dynamic Canopy Test Using LSC

Figure 26



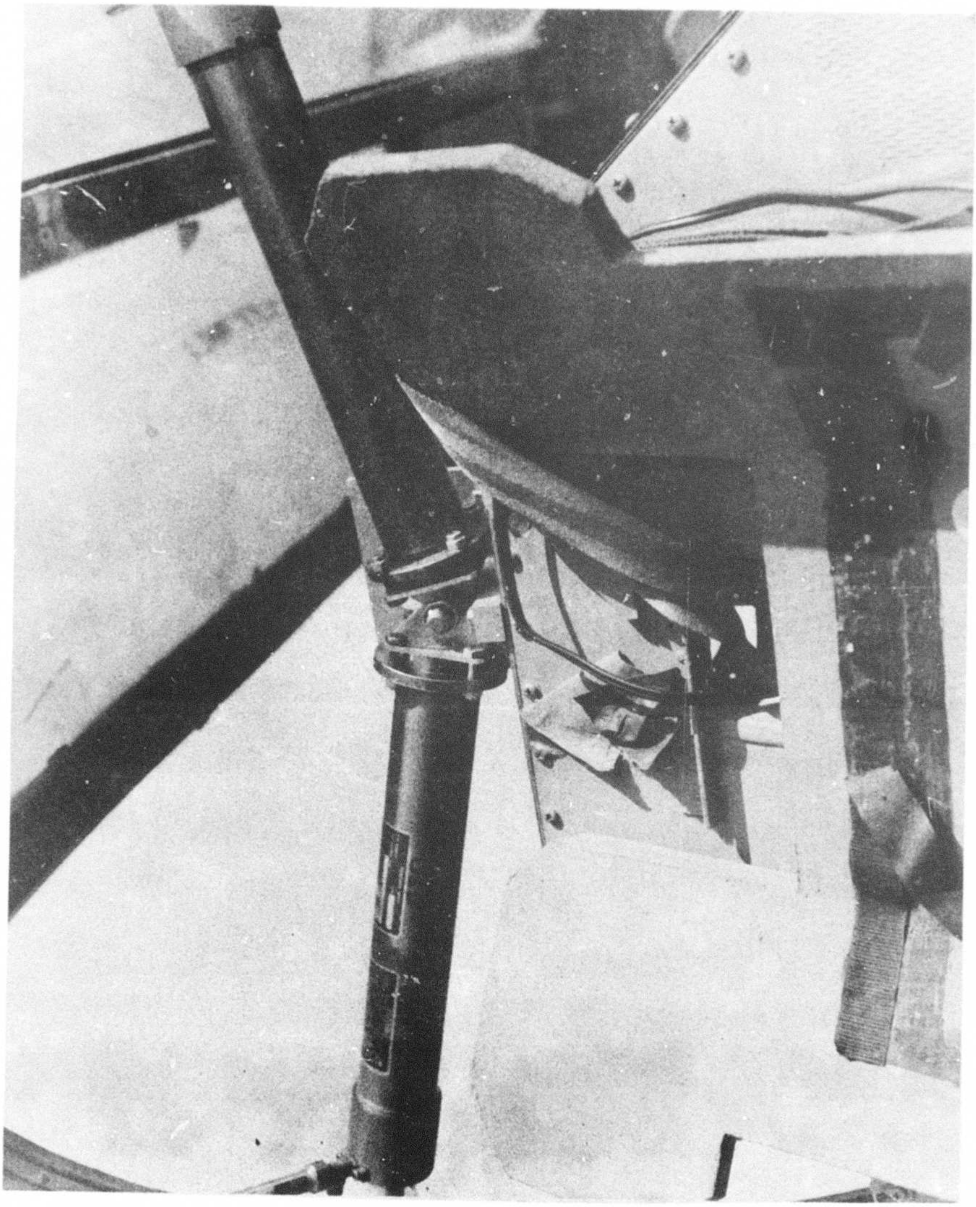
Set Up for Canopy Test Using Detonating Cord

Figure 27



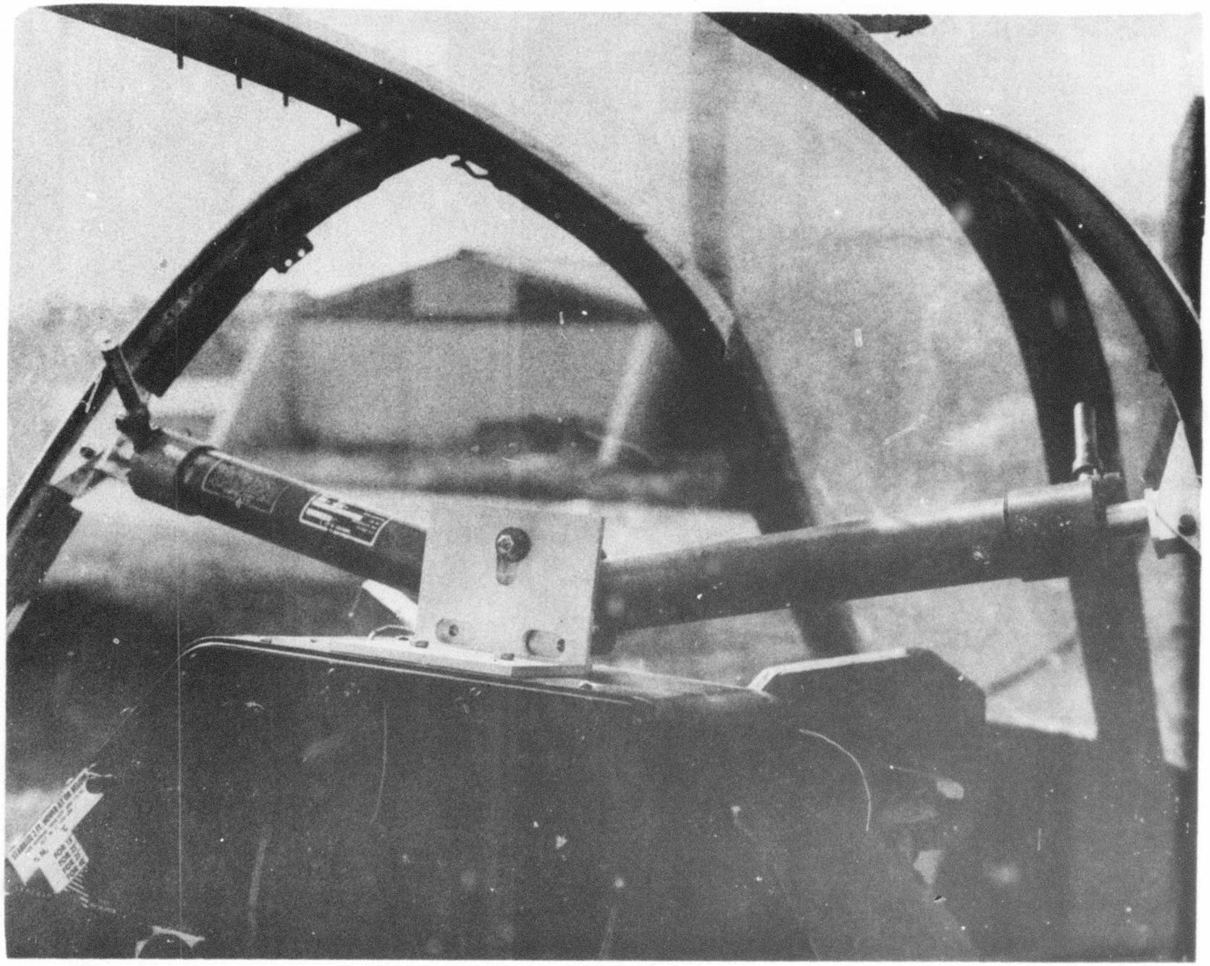
Explosive Tee

Figure 28



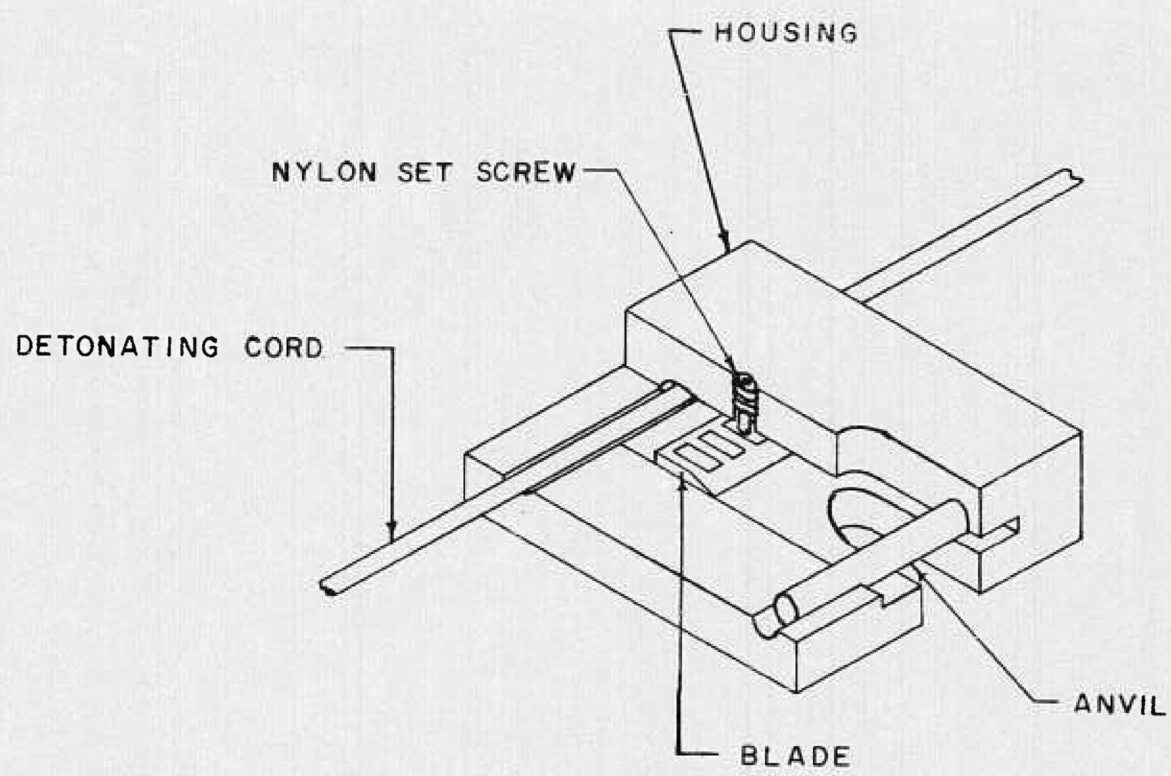
Aft View of M1A3 Remover Mount

Figure 29



Forward View of M1A3 Remover Mount

Figure 30



Cable Cutter

Figure 31

GUNSIGHT RETRACTION ASSEMBLY

In this program stowage of two gunsights was investigated. Figure 32 is the M28A1 gunsight used in the AH-1G and J helicopter models and Figure 33 is the TOW gunsight which will be used in the AH-1Q helicopter.

The base of the M28A1 sight is attached to the floor in the gunner's compartment between his feet. This sight is hinged at various points so that the gunner may move it anywhere within his cockpit to assist him in locating targets.

A static test was performed at NSWC/DL using a mock-up of the gunner's instrument panel and M28A1 gunsight fabricated to actual dimensions (Figure 34). The retraction device used was a ballistically operated cable take-up reel (Figure 35) for arm retention in the RA-5C aircraft escape system. The reel was mounted to the back of the simulated instrument panel. Figure 36 shows the successful post-test result. Complete retraction of the gunsight occurred in 187 milliseconds.

However, this device as presently designed will not be acceptable for operational use with the gunsight in the AH-1 helicopter. The final device used must maintain a given level of tension on the cable between it and the gunsight and it must be capable of retracting the gunsight from any position in the cockpit.

The original requirement was that the device should be capable of retracting the gunsight from any position, including the stowed position. The gunsight is held in the stowed position by a metal pin which would have to be sheared prior to the gunsight being retracted. After examining the gunsight in the stowed position a question arose as to whether the sight had to be retracted from this position. This question was never resolved by testing but it will simplify the design of the retraction mechanism if the sight does not have to be retracted when in the stowed position.

The TOW gunsight in the AH-1Q helicopter is an integral part of the forward airframe and it does not pivot at any point. No tests were run on this sight due to its cost and scarcity but it was felt that one technique would be to cut around its perimeter about 12 inches from the top with linear shaped charge and then retract the upper portion against the gunner's instrument panel. Another technique considered was the use of thrusters mounted on the side of the sight. Upon actuation of the thrusters, bolts which are used in assembly of the sight would shear allowing the upper 12 inches of the sight to be displaced forward.

Consideration also was given to the possibility that the sight might not have to be retracted at all since the sight eyepiece is directly above the forward edge of the gunner's seat. This could be determined by installing a TOW sight or a mock-up of one in the cockpit during extraction tests.

This development program was a joint NSWC/DL and Frankford Arsenal (FA) effort. The following design goals were established by NSWC/DL and FA for the M28A1 gunsight retraction device:

1. From initiation to full retraction 0.300 second.

2. Configuration to be suitable for mounting forward of gunner's instrument panel.

3. Provisions for dual electrical cartridges.

4. Maximum weight of four pounds.

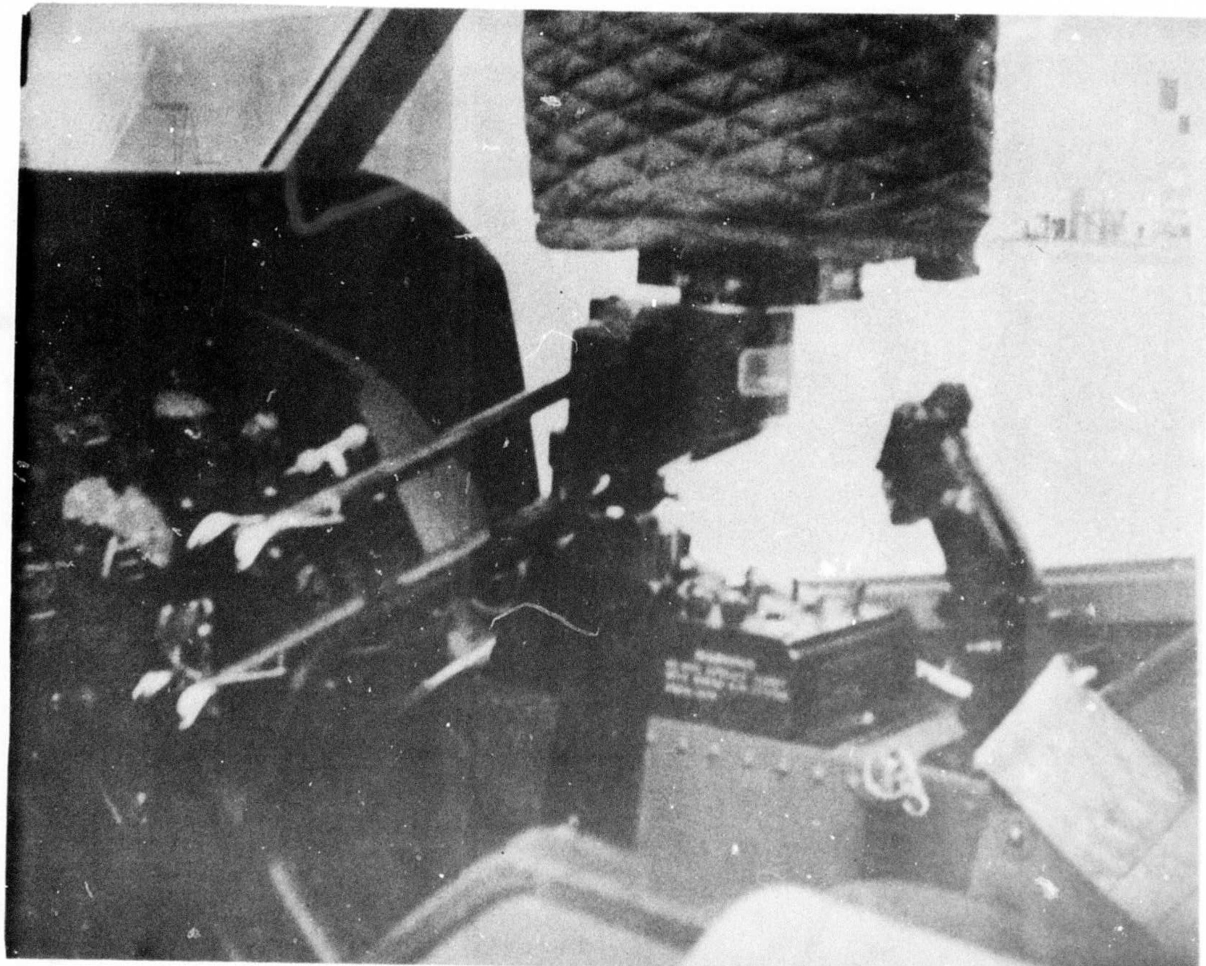
5. Maximum strap velocity (to be defined later).

6. Maximum volume 115 cubic inches.

7. A device providing constant and sufficient, but not restrictive, tension in cable at all times to prevent slack.

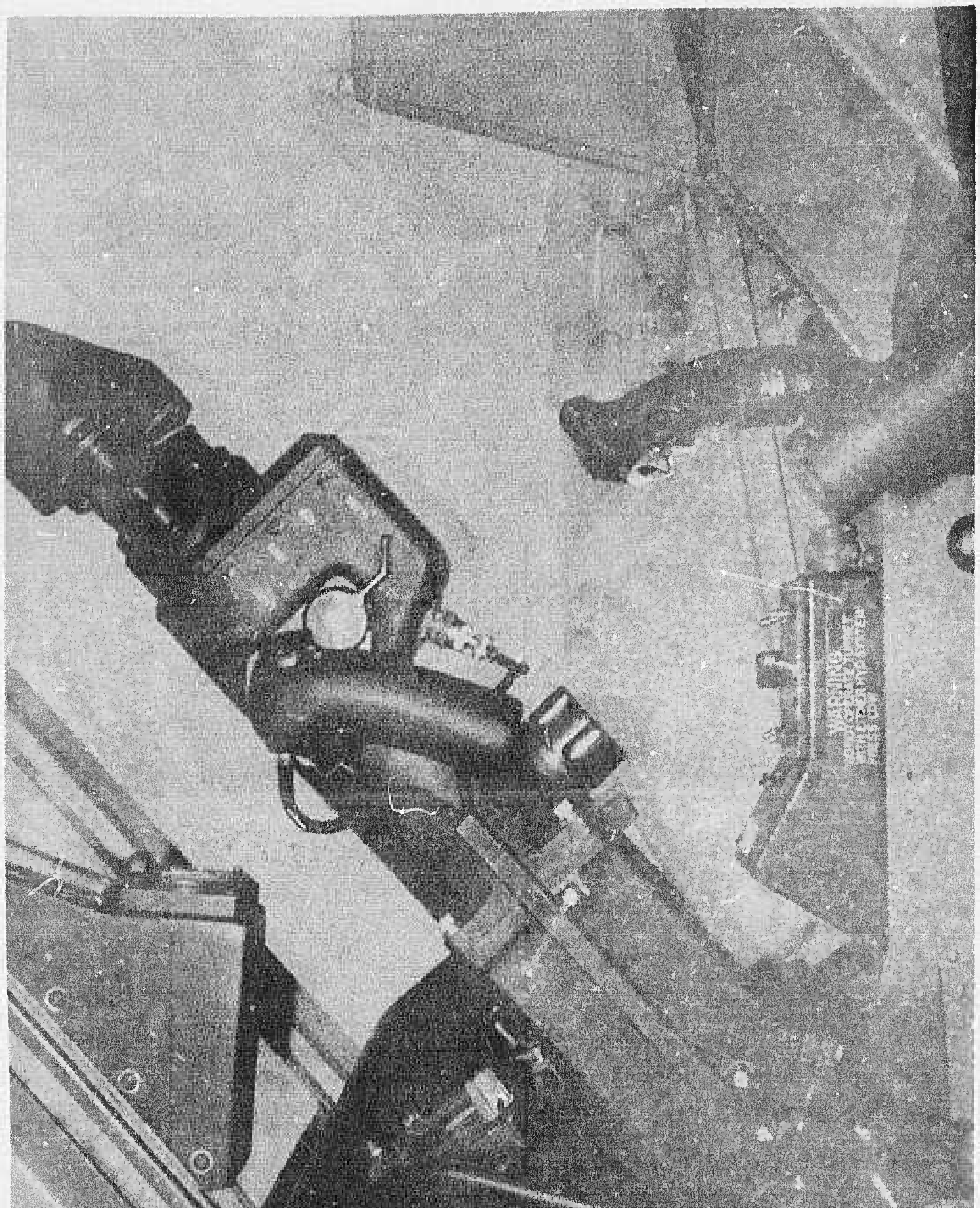
8. Device shall be capable of 35,000 cycles (from stowed position, to any other position, and back to stowed position is one cycle).

Preliminary device designs were prepared but no hardware components were fabricated.



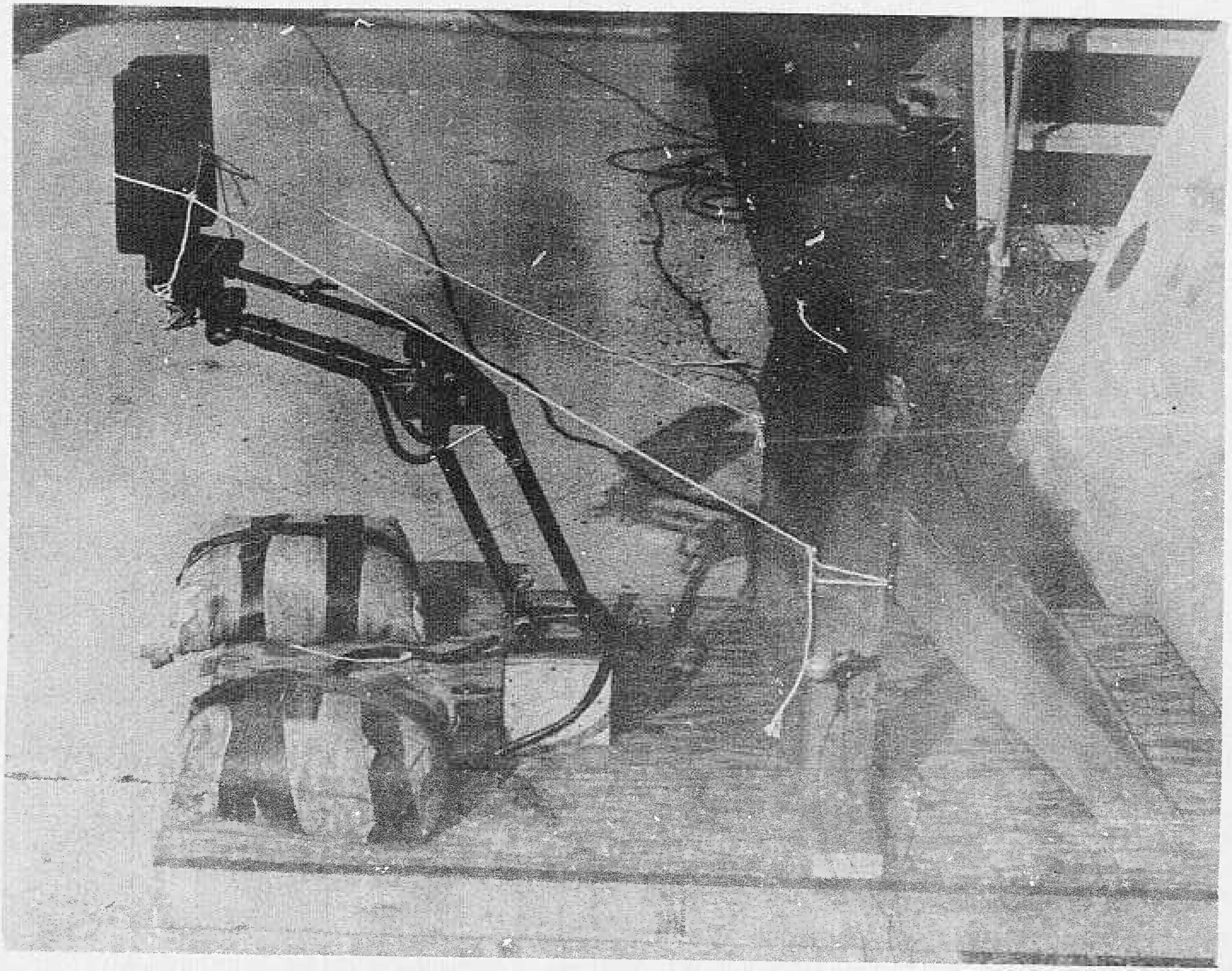
M28A1 Gunsight

Figure 32



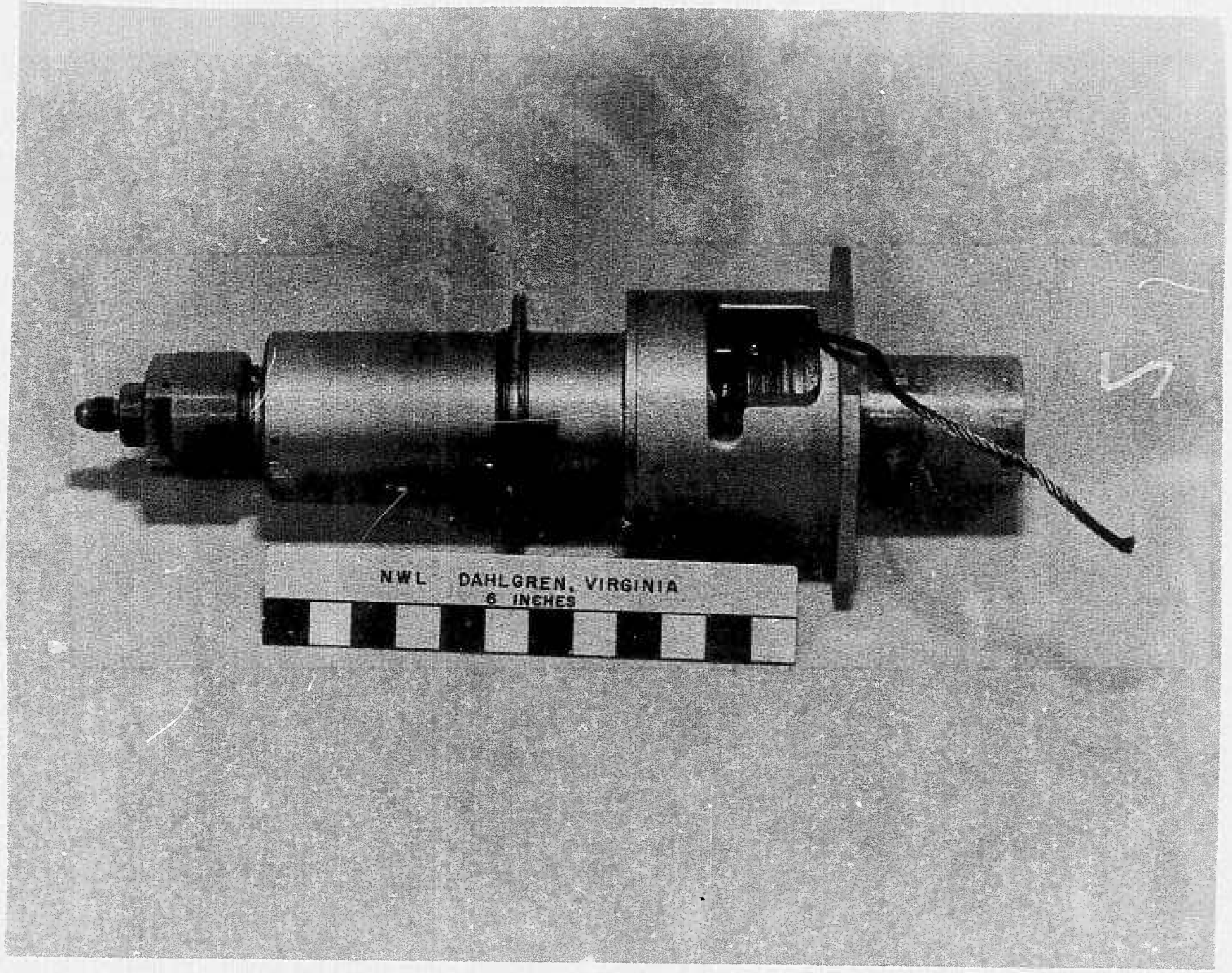
Tow Gunsight

Figure 33



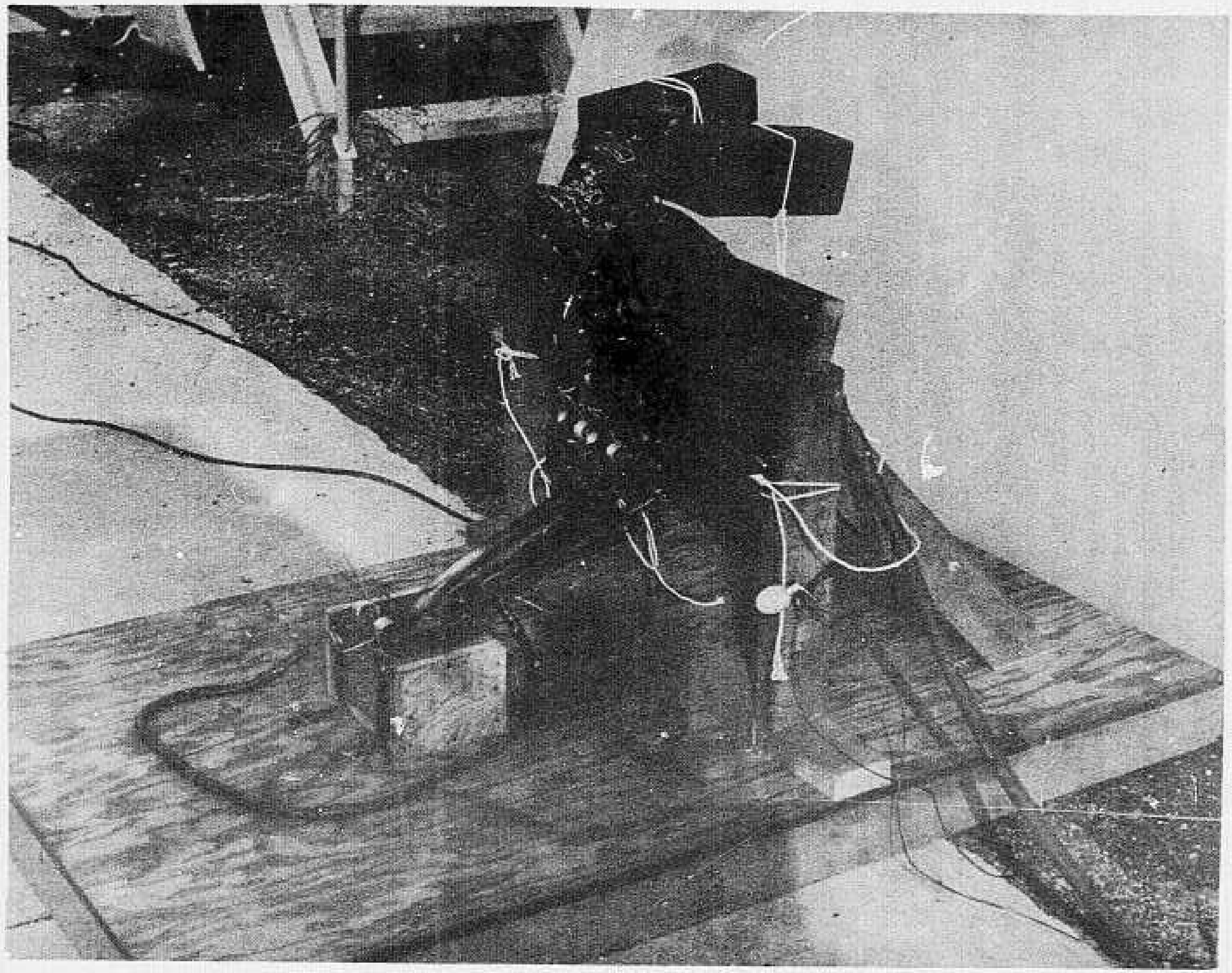
Pretest of M28 Retraction

Figure 34



RA-5C Arm Take Up Reel

Figure 35



Post-Test View of M28 Retraction

Figure 36

EXTRACTION ROCKET LAUNCHER ASSEMBLY

NSWC/DL was requested to recommend an interim launcher for use in the initial evaluation tests of the NWC (Naval Weapons Center) China Lake, California, extraction rocket. The device chosen for this task was the XM-7 cartridge actuated parachute ejector. This ejector as originally designed contained a percussion fired cartridge but it was modified by Frankford Arsenal, at NSWC/DL request, to contain an electrically fired cartridge. This was done to allow it to be used with the NWC rocket.

Figure 37 shows the interim design of the launcher with the rocket attached. It consists of two independent XM-7 ejectors which are screwed into an aluminum plate which is also used to mount the assembly in the aircraft. The rocket is attached to the base by two aluminum tensile pins which allow the ejector cartridges to build up pressure prior to rocket launch. A design goal of 120 feet per second rocket launch velocity was established.

However, as presently designed, the XM-7 is not the optimum launcher for the NWC rocket. Its design deficiencies are (1) it does not have dual primers or cartridges for redundancy, (2) the tubes (extended after firing) remain attached to the helicopter, presenting a collision hazard to the extractees, and (3) there is no interconnection between the dual launch tubes to provide redundancy and pressure equalization.

This launcher development was a joint effort between NSWC/DL and Frankford Arsenal.

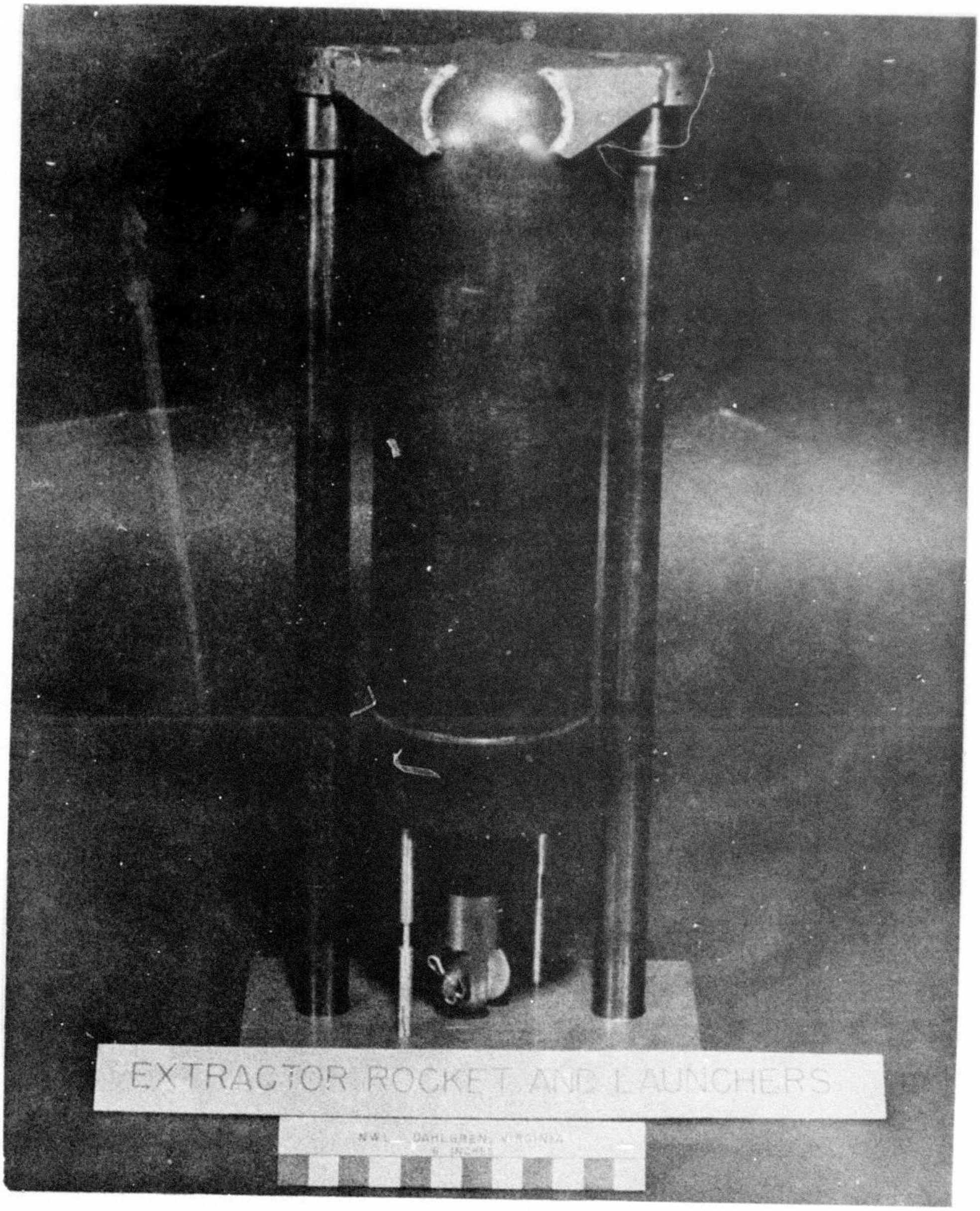


Figure 37

LAP BELT RELEASE

NSWC/DL was requested to provide an interim method of releasing the crewmen's lap belts from the fuselage during dynamic extractions. The method selected was to use two explosive bolts (Holex Part Number 2504-13) on each man's lap belt to connect the end fittings on the lap belts to the fittings attached to the fuselage. When an electrical impulse was provided the bolts sheared thus releasing the lap belt at each end.

This technique was used successfully for three dynamic dual extractions but it should not be considered for operational use because of the danger of fragmentation damage to the man's parachute from the bolts.

INITIATION, SEQUENCING, AND ENERGY TRANSFER ASSEMBLY

The initiation, sequencing, and energy transfer (ISET) assembly provides initiation energy to all escape system components in the proper sequence. The ISET must transmit energy in a predetermined sequence to all system functions including, but not limited to:

- rotor severance
- canopy jettison
- gunsight retraction
- fuel shutoff
- escape subsystem.

The initial NSWC/DL studies described a single electronic sequencer (Figure 38) as the heart of the ISET system. The electronic sequencer employed digital electronics to count time and release electrical energy to individual functions as desired. Use of the electronic sequencer would provide a much more precise sequencing capability than otherwise possible. Due to development problems that appeared in other programs using the electronic sequencer, the risks of using the sequencer as the prime sequencing method were reevaluated. In spite of the long term potential, it was decided that the electronic sequencer would be relegated to backup status and a less innovative sequencing method was chosen.

A trade-off study to determine the optimum ISET configuration was conducted and some of the findings are outlined in Table 1. This analysis revealed that a hybrid sequencing and energy transfer assembly appeared to be optimum. The trade-off effort was continued as part of the program to ensure that the optimum means of energy transfer was used in the final design. In brief, the hybrid assembly (Figure 39) will use redundant ballistic gas initiators at each crew station. The gas pressure pulse will primer fire redundant thermal batteries which will initiate the canopy jettison assembly. The pressure pulse will be transmitted aft to the redundant mast thermal batteries. In addition to providing energy for the rotor severance assembly, these thermal batteries initiate gas generators which apply pressure to the gas fired rocket launcher and lap belt release initiators at each station. The following detailed description requires referral to Figure 39.

The escape system's primary initiators will be "D" rings located on the center of the forward edge of each seat bucket. The top of

TABLE 1

ENERGY TRANSFER TRADE-OFF ANALYSIS

	Ballistic Gas Hose		SMDC		Electrical
1.	Non-explosive	1.	Explosive (Class A material)	1.	Non-explosive
2.	No special <u>handling</u> or <u>packaging</u> required	2.	Special <u>handling</u> and <u>packaging</u> required	2.	No special <u>handling</u> or <u>packaging</u> required
3.	Simple structural design	3.	Moderate explosive design complexity	3.	Moderate design complexity
4.	Relatively long delays for gas pressure to develop and move through a hose	4.	Detonation wave moves instantaneously over distances involved	4.	Time delay to bring thermal battery on line is only delay (100 ms)
5.	Delay elements accuracy ±25%	5.	Delay elements accuracy ±25%	5.	Delay elements accuracy ±5% or less
6.	System sequencing changes would be difficult and expensive	6.	System sequencing changes would be difficult and expensive	6.	System sequencing changes would be easy and relatively inexpensive
7.	Complex event sequencing carries significant weight and size disadvantages	7.	Complex event sequencing carries significant cost disadvantage	7.	Complex event sequencing relatively easy
8.	Good service history	8.	Limited service history in this application with probable "teething" problems	8.	Limited service history in this application with probable "teething" problems
9.	Direct interface Initiator Cartridge — 1 Hose — CAD	9.	Four explosive interfaces Initiator Tip — 1 — SMDC Tip — 2 — SMDC — 3 — SMDC Tip — 4 — CAD	9.	Two interfaces Battery — 1 — Sequencer — 2 — CAD
10.	Indefinite service life	10.	Limited service life. Will require periodic replacement	10.	Indefinite service life
11.	Virtually unaffected by enviroments except temperature (heat losses of gases)	11.	Significantly more affected by environments	11.	Virtually unaffected by environments

TABLE 1 (CONT'D)

Ballistic Gas Hose	SMDC	Electrical
12. Little or no material compatibility problems	12. Due to use of metals, chemical explosives, more likely to have compatibility problems	12. Little or no material compatibility problems
13. Flexible, good interchangeability	13. Semi-rigid, poor interchangeability	13. Flexible, good interchangeability
14. Has limitations in multiple outputs	14. Good multi-output capability	14. Severe limitations in multiple outputs can be avoided with a weight penalty
15. Limited redundancy	15. Good redundancy	15. Good redundancy
16. Limitations in long transmissions	16. Good long transmission capability	16. Limitations in long transmissions can be avoided with a weight penalty
17. Relatively heavy	17. Lightweight but no significant advantage except in large network	17. Weight is dependent on number of outputs
18. --	18. Significant advantage in size particularly as length and number of lines increases	18. Advantages in size decrease with increase in complexity
19. No extensive qualification involved	19. Extensive qual. involved, but will decrease with additional applications because of similarity	19. Extensive qual. required in this application due to new application of technique
20. There is existing spec. and QPL list	20. Would more likely be proprietary	20. No existing spec. and QPL for items with required reliability except in space applications
21. 100% non-destructive production testing (pressure tests)	21. 100% production X-ray and destructive testing samples	21. 100% non-destructive testing

TABLE 1 (CONT'D)

Ballistic Gas Hose	SMDC	Electrical
22. Minimizes supply inventory	22. Will significantly increase inventory	22. Increase supply inventory
23. Good availability since hose also used in aircraft hydraulics system	23. Limited availability	23. Good availability of hardware
24. Minimum documentation	24. Significant increase in procurement documentation	24. Minimum documentation except for sequencer
25. Cheap unit costs with little forced replacement	25. Significantly more expensive especially when considered over the aircraft life	25. Cheap unit costs with little forced replacement

the "D" ring will be below the level of the compressed seat cushion and sufficiently forward of the survival kit, or seat bucket structure, to permit the handle to be readily grasped. The initiator will incorporate a retention system capable of preventing accidental firing of the escape system under dynamic loads and during normal ingress and egress from the cockpit.

The firing unit will use two M99 initiators (Figure 40) as the gas producing items. The M99's will be configured with a common "D" ring handle so that both firing pins would be pulled by a single handle stroke. Each system initiator will produce dual, redundant, independent gas signals.

The ballistic gas pressure is transmitted through Teflon-lined aircraft hose with exterior wire braid in accordance with MIL-H-25579. This hose is "off-the-shelf" from many commercial suppliers.

As the pressure pulse passes the aft crew station, gas will be bled off to initiate the canopy jettison function. The operation of this function will be described later. Beyond the aft crew station a M53 "booster" initiator (Figure 40) drives a gas pulse to a unit located within an existing cavity in the aircraft transmission. This location was chosen because of the protection afforded the mast battery unit by the transmission. This gas pulse propels firing pins into dual, redundant thermal batteries mounted in the mast battery unit. The earliest ISET trade-offs had established that the rotor severance function would be best accomplished by electrical means. Study of the original analysis failed to reveal any definite advantages of using ballistic gas or shielded mild detonating cord (SMDC) for rotor severance.

The thermal battery intended for use in the ISET system is the Catalyst Research Corporation P/N 404510 or equivalent (Figure 41). This battery has reportedly demonstrated the ability to initiate five 1 amp - 1 watt no-fire detonators within 0.100 second of primer hit.

The thermal battery unit supplies electrical energy to initiate three actions:

1. Rotor Severance Assembly - The electrical energy is transmitted through twisted shielded pairs of wires to a slip ring unit (Figure 42) mounted directly underneath the mast nut. The slip ring contains two circuits, one designated as primary and the other as backup. Due to the construction of the slip ring the

primary rotor severance circuit can be electrically completed only when the blades are at a predetermined position. The primary circuit is designed this way to start the severed blades in predetermined directions relative to the aircraft. The backup circuit is continuously "made" so that whenever the backup thermal battery starts generating electricity, the blades will be severed regardless of blade orientation. The 0.100 second delay initiator inserted between the two thermal batteries provides the time interval during which the blades should pass through the optimum blade severing position. If, for any reason, the blades fail to pass through the optimum blade severing position in 0.100 second or the primary system should fail, the backup mode will sever the blades. Regardless of the circuit used through the slip ring unit, each circuit exits the mast nut through a military standard qualified connector. The circuit goes to a junction box unit (Figure 43) where the circuit is branched, in this case to two FMU-118A detonators (Figure 44). The junction box unit is provided so that all electrical connections are shielded at all times. A printed circuit board is employed as the method of electrical connection between the circuits. The FMU-118A detonator has been specially designed for initiating the two linear shaped charges (LSC) required for the rotor severance assembly. The detonators have a main charge of 445 milligrams of HNS II explosive and the detonator on each circuit is located at each LSC.

2. Fuel Cut Off Valve(s) - These electrically initiated items would be operated upon actuation of the rotor severance assembly. The valve has not been designed since an off-the-shelf solenoid valve was used during tests.

3. Escape Subsystems - Twisted, shielded pairs of wires go forward to initiate dual, redundant electric initiators which in turn fire M53's. The gas pulse of the M53 initiators is transmitted through ballistic gas hose to a delay initiator. This delay initiator will be inserted if found to be necessary for ensuring blade/man separation. The delay initiator appears to be necessary but subsystem tests would be required prior to a decision. Whether the delay initiator is inserted or not, the dual and redundant gas pulses are delivered to the gas fired rocket launcher and lap belt initiators located at each crew station.

The initial system trade-offs led to a ballistic gas system design for the canopy jettison assembly. A review of the advantages of the use of thermal batteries in the rotor severance area led to thoughts that possibly other specific functions could be initiated electrically with an attendant weight advantage and a reduction of system complexity. A trade-off analysis revealed the canopy jettison area was another opportunity for substitution of a relatively lightweight and simple thermal battery and electric detonator subsystem. Study showed that no additional savings could be realized by thermal battery insertion in other system areas. The thermal battery intended for use in the canopy jettison assembly would be the same size and capacity as the battery used in the rotor severance assembly. The battery would be overpowered for the canopy jettison assembly but the weight saving of a smaller battery is minimal compared with the problems of logistics support of two different thermal batteries. The thermal battery would be used in a different housing than when used in the rotor severance assembly but would still be primer fired by a ballistic gas pressure pulse. Each canopy jettison thermal battery will initiate three items:

1. Gunsight Retraction Initiator - This initiator will be similar to the existing MARK 17 ignition element. Figure 46 depicts the assembly of the initiators. Gas pressure from either independent initiator will fire the retraction reel.

2. FMU-119A Detonator - This detonator (Figure 44) has been designed to initiate the detonating cord (det cord) used to effect cutting of the canopy glass and frame members. The FMU-119A detonator has an output charge of 92 milligrams of HNS II explosive. The FMU-119A has been designed with all practical steps taken to prevent inadvertent interchange with the FMU-118A detonator. One FMU-119A detonator is located at each end of the continuous length of det cord so that initiation of either detonator will result in detonation of the entire run of det cord.

3. Canopy Remover Initiator - The initiator will be similar to the MARK 17 ignition element. Figure 47 shows assembly of the initiators. Gas pressure from either independent ignition element will fire both canopy removers.

Figure 39 shows a canopy jettison assembly consisting of three M99 initiators and several lengths of aircraft hose. The internal M99 initiators will be mounted on or near each crew station instrument panel. This assembly enables either seated crewman or a person outside the aircraft (at the nose) to fire the canopy jettison assembly. It appears to be impractical to put the external initiator on AH-1Q aircraft due to the lack of space in the nose of this aircraft. Actuation of one of the M99 initiators will primer fire both redundant thermal batteries resulting in jettison of the aircraft canopy and retraction of the gunsight. Actuation of this system will not degrade performance of the full escape system if it is selected at a later time. Use of the canopy jettison assembly allows the selection of canopy jettison while in flight, a capability not assured with the present "ground escape" system in use on some AH-1J aircraft.

The following discussion addresses the ballistic and electrical items employed in the ISET and delineates applicable design considerations.

1. Ballistic Gas Items - Many of the individual gas producing items planned for use in the ISET system are "off-the-shelf" and qualified in accordance with certain military specifications. The larger items (M99 and M53 initiators) are presently in use in every fixed-wing aircraft escape system today (except for the F-14) and would require minimal component testing. The other items would require various amounts of design (or redesign) and test.

a. Ignition Element. A common ignition element should be developed to function at any of three places (gunsight retraction initiator, canopy remover initiator, and the initiator coming forward from the mast battery unit). The gas pulse required for the three functions is nearly similar and an intentionally common element would reduce design, qualification and logistics support necessary for more than one item. One item would also reduce mechanical "murphy-proofing" efforts. It appears that the existing MARK 17 ignition element can be used in all applications but testing would be required for verification.

b. Delay Initiator (0.100 Second). This initiator is used with the mast battery unit to provide the time delay between the primary and backup rotor severance events. The 0.100 second delay initiator in the mast area will use a modified CCU-36/A 0.100 second delay cartridge currently under final development by the Naval Ordnance Station, Indian Head, Maryland. The output charge of the CCU-36/A would need to be reduced significantly as it is excessive for the requirements of the AH-1 ISET system.

Examination of CCU-36/A test results indicate that the nominal time delay and the tolerance on the time delay over the temperature range -65°F to +200°F are satisfactory for the AH-1 ISET application.

c. Delay Initiator (time to be determined). This initiator is located between the M53 initiator and the individual crew station rocket launcher/lap belt assembly. The necessity for this delay initiator has not been determined and even the nominal time delay (and delay tolerances) has not been determined. Every effort must be made to use an "off-the-shelf" delay train when the requirements become known.

d. Gas Hose Network. The prime considerations while routing the gas hose network have been (in descending order): system reliability (mostly redundancy considerations), weight, and system complexity. Generally, the more redundancy included, the more aggravated the weight and complexity problems become. It is planned that the redundant gas lines go forward and aft on opposite sides of the aircraft. Between the aft crew station and the aircraft transmission, the hoses must circumvent the main fuel cell. In this area it is anticipated that, in addition to being on opposite sides of the aircraft, one hose will go underneath and the other will go over the top of the fuel cell. Use of one-way check valves will ensure that gas pressure will not be wasted pressurizing unnecessary hose volume, thereby maintaining the required gas output from each item.

The gas hose network is the portion of the gas system that will require the most testing as it must be tested in all possible modes. Each component, each component with its associated gas line (configured as in the aircraft), all-up system tests (also configured as in the aircraft), and system and subsystem tests using "dead" initiators to simulate failure of one of the dual items must be conducted. This final series of tests is critical to assure that the gas hose network is truly redundant on all runs. Pressure transducer readings will be taken on every test to assure that no hose runs are marginal under any test condition. Gas operated firing mechanisms have been used in numerous applications over the past 15 years and proven concepts and assemblies will be used.

2. Electrical Items - Electrically initiated ordnance items have been used for years in aircraft weapons systems. They have found their greatest acceptance in rocketry and it was the space program which finally developed the data and expertise to fly a man-rated electrically initiated escape system. Currently, no aircraft escape system uses electrical items in such critical areas as intended for the IFES. Confidence in electrical systems for personnel escape stems from two facts.

a. Reduction of the system to the simplest possible design. By hard-wiring the battery and its associated items together, most failure modes have been removed.

b. Advance in the state-of-the-art of electrical systems.

Design and qualification of 1 amp - 1 watt capable items, establishment of a HERO (Hazards of Electromagnetic Radiation on Ordnance) program, and the pioneering work in the space and missile fields in the design of thermal batteries are indicators which point to the probable acceptability of the use of thermal batteries and other electrical items in aircraft escape systems.

One important advantage of using electrical items is that the continuity of the electrical circuits can be verified as opposed to systems that use mild detonating cord as the transfer medium.

The greatest single problem with the digital electronic sequencer was its relatively high sensitivity to "single point failure" because either too short or too long a delay between events could be equally disastrous. The system layout presented in Figure 39 seeks to preclude a single point failure from degrading system performance.

Of the electrical items shown in Figure 39 and discussed below, not one item intended for use is currently qualified to applicable military specifications.

1. Initiator - The common initiator discussed earlier is one of the interfaces between the electrical portion and the gas portion of the ISET. The electrical requirements appear to be identical for the three functions addressed previously, further indicating the practicality of a single item being used three places in the system.

2. Thermal Battery - A candidate thermal battery has been found which is stated to reliably initiate five 1 ohm, 1 amp - 1 watt capable bridgewires within 0.100 second. The external design would necessarily change to allow the steel battery case to be used as the battery assembly housing but these changes would not affect the electrical output of the battery. Tests would be necessary to prove that the six items to be fired by the mast batteries in dual engine aircraft would fire within the required time limit.

3. FMU-118A Detonator - The FMU-118A detonator has been designed, constructed, and subjected to extensive tests. The detonator appears ready for qualification.

4. FMU-119A Detonator - The comments relative to the FMU-118A detonator apply to the FMU-119A also.

5. Junction Box - The junction box assembly is required so that electrical connections take place inside a metal enclosure to preclude HERO effects. Figure 43 shows the design evolution of the junction box and Figure 45 shows the components of the latest design. The first design weighed 1.8 lbs and the last design weighs approximately 0.2 lb. After the wires are soldered to the circuit board and the wire shields are soldered to the brass headers, 100 percent nondestructive continuity checks will establish the

acceptability of the assembly. The cavity in the body will be filled with a potting compound to reduce the adverse mechanical effects of vibration and then the back plate will be permanently affixed to the body. The junction box assembly will consist of the junction box, the number of wire pairs required for the application, and electrical connectors terminating the wire ends.

6. Electrical Connectors - The electrical connectors chosen for the AH-1 ISET must meet exacting standards. A new military specification or an adaptation of an existing military specification will be necessary to define these standards. Presently there is no single document that controls electrical connectors for this application. Commercially available connectors may operate satisfactorily with little or no modification, which would reduce or eliminate any development effort in this area.

7. Electrical Wire - Electrical wire for this application is "off-the-shelf" from many commercial vendors in accordance with existing military specifications. Reference of appropriate specifications will result in procurement of satisfactory wire. The wire used on tests to date has been twisted pairs of 16 gauge stranded copper with Teflon insulation inside a single braided shield layer and a plastic tape outer layer. The wire gauge is subject to revision based on load and resistance trade-offs. The thermal battery qualification tests would be used to provide data for these trade-offs. A second braided shield layer would be added on all wire runs where maximum flexibility is not required. A fabric outer layer would be substituted for the single plastic tape wrap presently used.

The ISET assembly as described in this document has several features of its layout and function which are not immediately obvious. One of these features is that the prime consideration of the system design was an attempt to combine system reliability and crew safety in the unlikely event of a partial system failure. Close inspection of Figure 39 will reveal that the following failures have been considered and safeguards then designed into the assembly.

SCENARIO

Assume an AH-1 aircraft crew desires to use the in-flight escape system when critical ISET components have sustained damage.

ANALYSIS

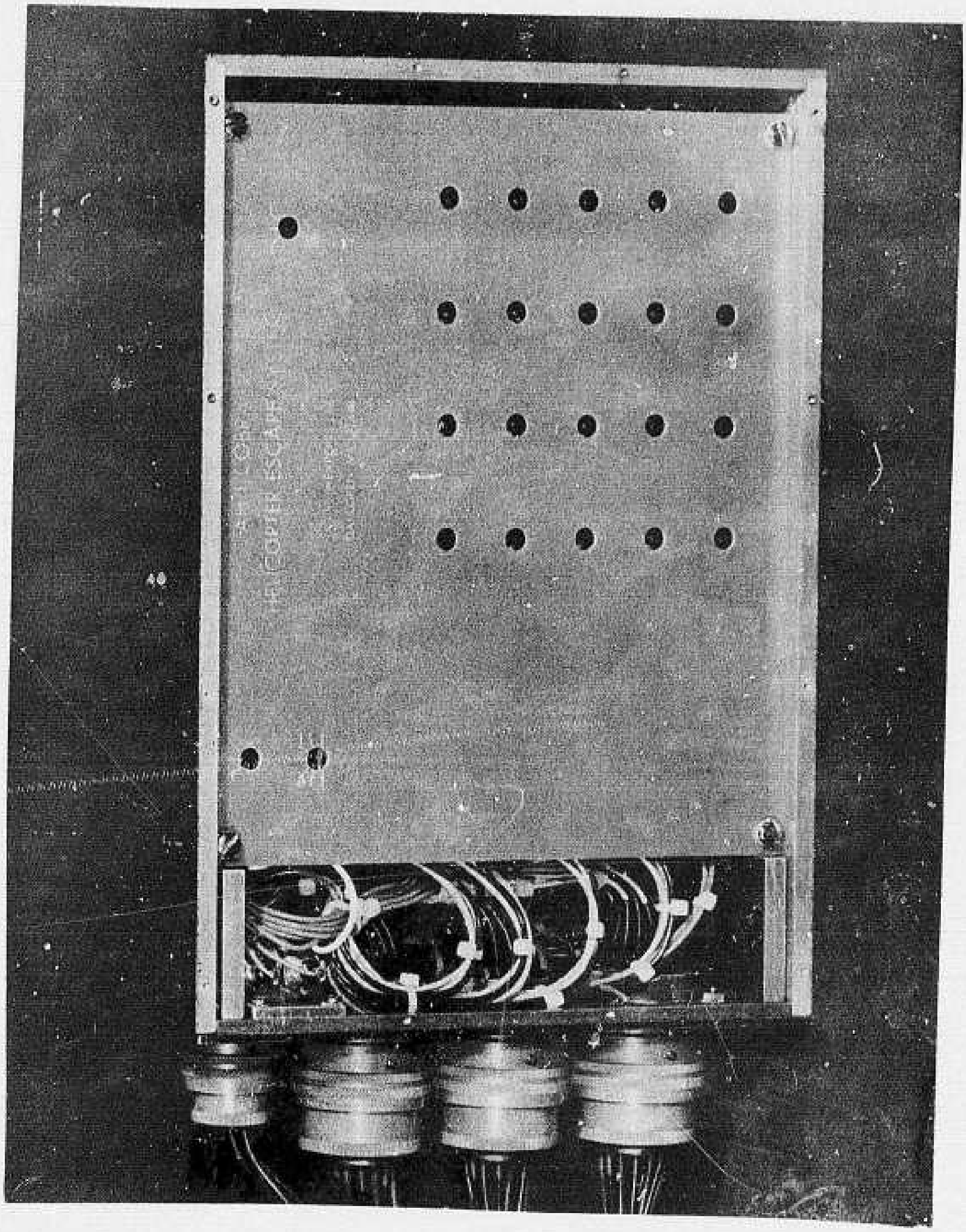
Either crewman pulls the "D" ring on his system initiator. Due to redundant gas lines, puncture of any single gas line leading from either system initiator will have no effect on the other half of the system. Gas pressure at the thermal battery and M53 booster will be equalized between hose networks by a gas line between the canopy thermal batteries. Catastrophic failure of this connecting hose would bleed pressure not only from the thermal batteries but also from the M53's, thus stopping the entire system. Although this result is undesirable, it is better than the alternative, i.e., actuation of the M53's and therefore the remainder of the system without the canopy being jettisoned. The purpose of this critical length of hose is to provide redundancy between the thermal batteries of the canopy jettison assembly. This hose will be approximately three feet long and less than 0.5 inch outside diameter. The hose serves its intended purpose when one side of the gas network fails by ensuring that both thermal batteries receive firing impulses from the working half of the gas network. The hose would run athwartships through the pilot's instrument console and would tend to be protected from fragmentation damage by the console instruments. It is felt that the benefits accruing from the presence of a whole line far outweigh the disadvantages presented by a failed line.

Once either (or both) M53 fires, it (or they) will provide gas pressure to both the primary mast thermal battery and the 0.100 second delay initiator and thus to the backup mast thermal battery. Either battery will be capable of initiating the maximum of six 1 ohm bridgewires wired to it without the aid of the other battery. The mast battery unit itself is well protected by being placed inside the aircraft transmission. The wiring to the slip ring and the slip ring unit itself are inside the aircraft mast and use the mast as electrical protection from HERO and mechanical protection from damage by fragments. Fragmentation damage can certainly occur to the junction box and the mast nut connector and that is the reason for two independent mast nut connectors, junction boxes, and LSC detonator circuits.

Firing of the ignition elements going forward in the aircraft and ignition of the M53 initiators will start the train of events leading to firing of both rocket launchers. Failure of one side of the gas network will not degrade system performance. Use of dual, redundant gas operated primers in the rocket launchers and lap belt initiators will increase the reliability of these items.

The block diagram (Figure 48) and the previous discussion show how the ISET assembly attempts to provide every reasonable possibility for total system performance and, in the case of massive damage to ISET components, system action will be stopped rather than allowing the worst kinds of malfunction, i.e., (a) rocket firing (and thus extraction) with the aircraft canopy still attached or (b) rocket firing (and thus extraction) without the rotor severance function having been performed.

The ISET assembly described in this document is estimated to weigh 19 pounds.



Electronic Sequencer

Figure 38

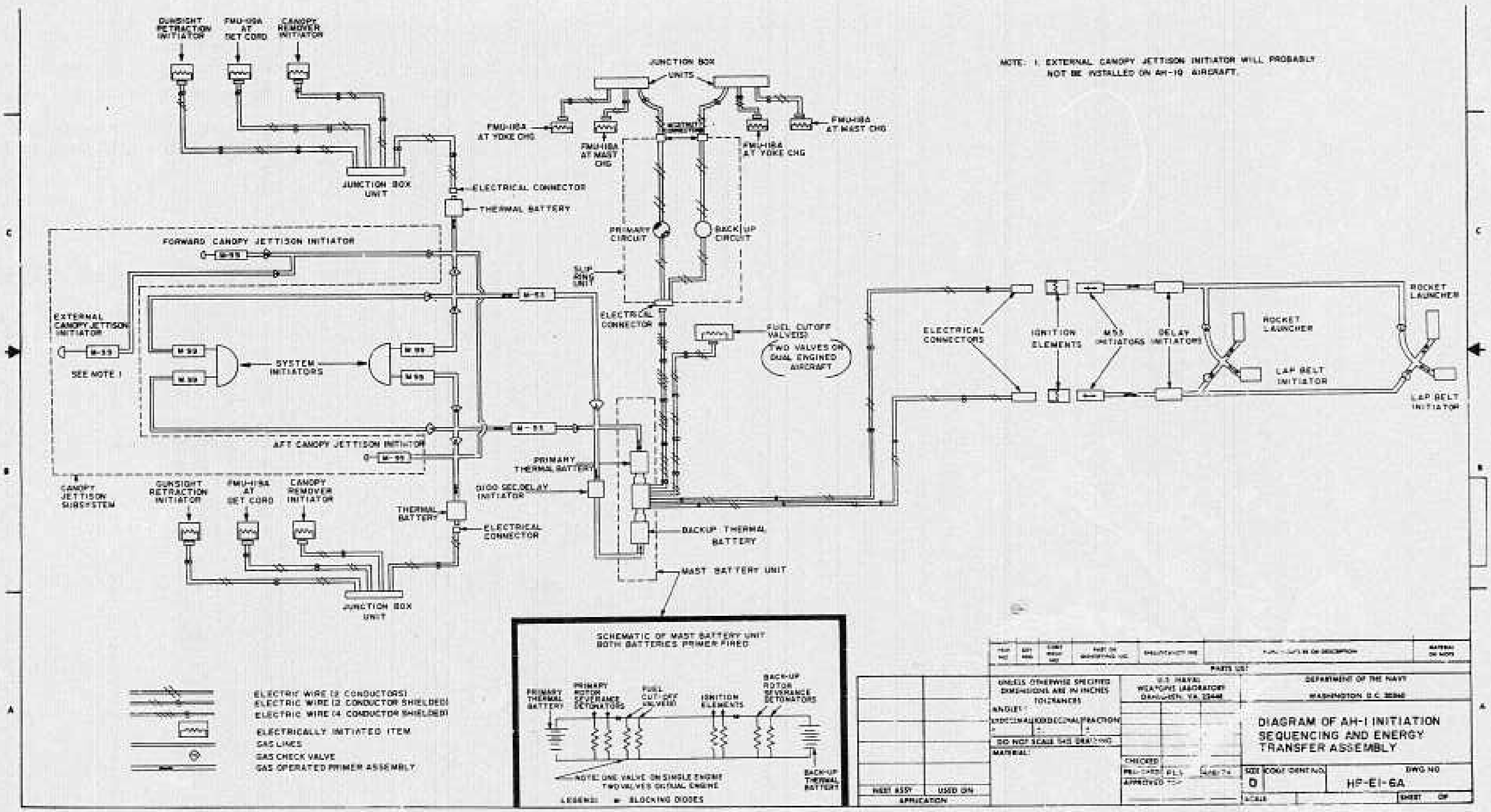
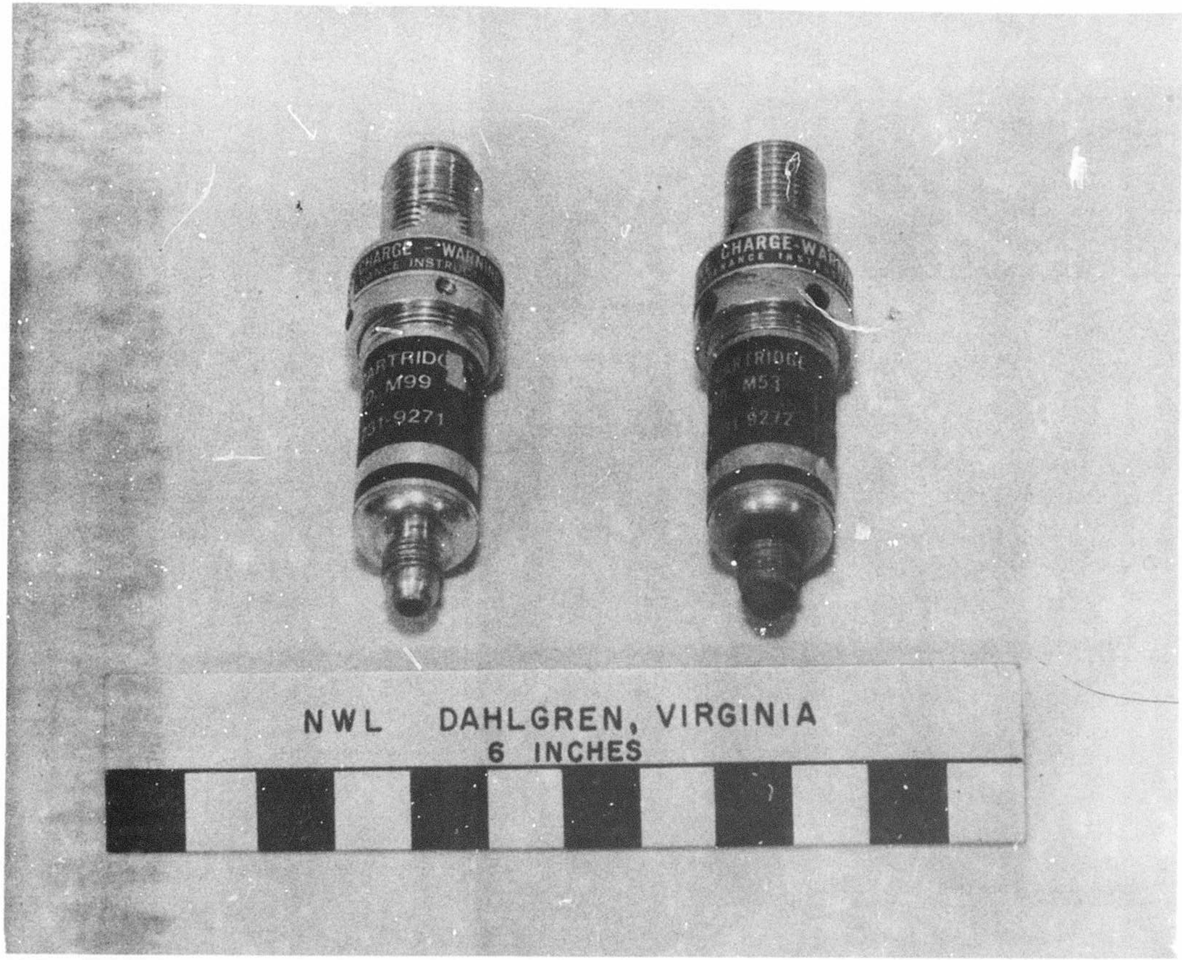

GUNSIGHT RETRACTION INITIATOR
FMU-119A AT DET CORD
CANOPY REMOVER INITIATOR
JUNCTION BOX UNIT
ELECTRICAL CONNECTOR
THERMAL BATTERY
FORWARD CANOPY JETTISON INITIATOR
EXTERNAL CANOPY JETTISON INITIATOR
SEE NOTE 1
SYSTEM INITIATORS
AFT CANOPY JETTISON INITIATOR
CANOPY JETTISON SUBSYSTEM
JUNCTION BOX UNITS
FMU-118A AT YOKE CHG
FMU-118A AT MAST CHG
PRIMARY CIRCUIT
BACKUP CIRCUIT
SLIP RING UNIT
PRIMARY THERMAL BATTERY
DIGO SEC.DELAY INITIATOR
BACKUP THERMAL BATTERY
MAST BATTERY UNIT
FUEL CUTOFF VALVE(S)
TWO VALVES ON DUAL ENGINED AIRCRAFT
ELECTRICAL CONNECTORS
IGNITION ELEMENTS
M53 INITIATORS
DELAY INITIATORS
ROCKET LAUNCHER
LAP BELT INITIATOR
NOTE: 1. EXTERNAL CANOPY JETTISON INITIATOR WILL PROBABLY NOT BE INSTALLED ON AH-1Q AIRCRAFT.
SCHEMATIC OF MAST BATTERY UNIT BOTH BATTERIES PRIMER FIRED
PRIMARY THERMAL BATTERY
PRIMARY ROTOR SEVERANCE DETONATORS
FUEL CUT-OFF VALVE(S)
IGNITION ELEMENTS
BACK-UP ROTOR SEVERANCE DETONATORS
BACK-UP THERMAL BATTERY
NOTE: ONE VALVE ON SINGLE ENGINE TWO VALVES ON DUAL ENGINE
LEGEND: BLOCKING DIODES
ELECTRIC WIRE (2 CONDUCTORS)
ELECTRIC WIRE (2 CONDUCTOR SHIELDED)
ELECTRIC WIRE (4 CONDUCTOR SHIELDED)
ELECTRICALLY INITIATED ITEM
GAS LINES
GAS CHECK VALVE
GAS OPERATED PRIMER ASSEMBLY
U.S. NAVAL WEAPONS LABORATORY DAHLGREN, VA. 22448
DEPARTMENT OF THE NAVY WASHINGTON D.C. 20360
DIAGRAM OF AH-1 INITIATION SEQUENCING AND ENERGY TRANSFER ASSEMBLY
HP-EI-6A

Figure 39



M99 and M53 Initiators

Figure 40

Thermal Battery

Figure 41

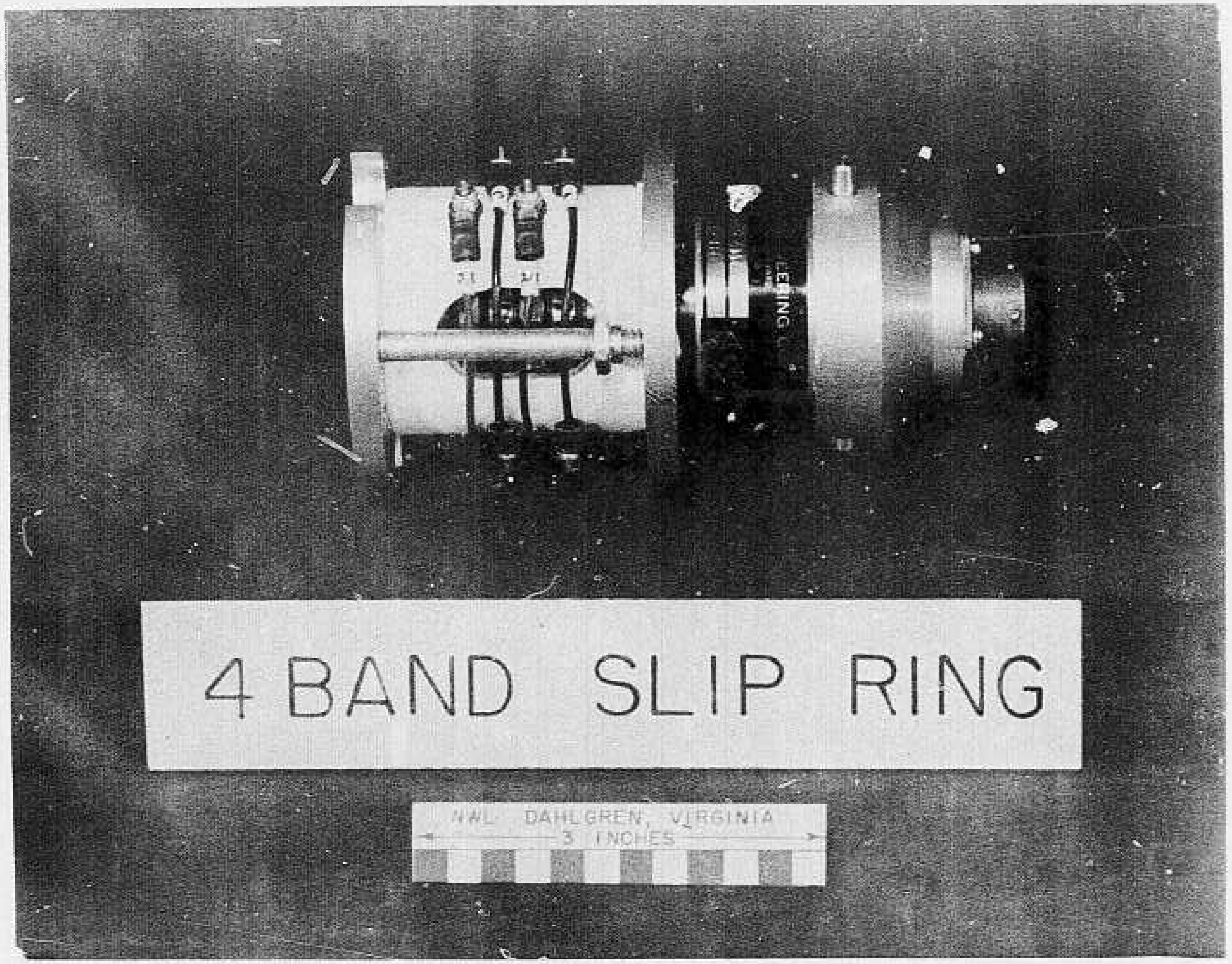
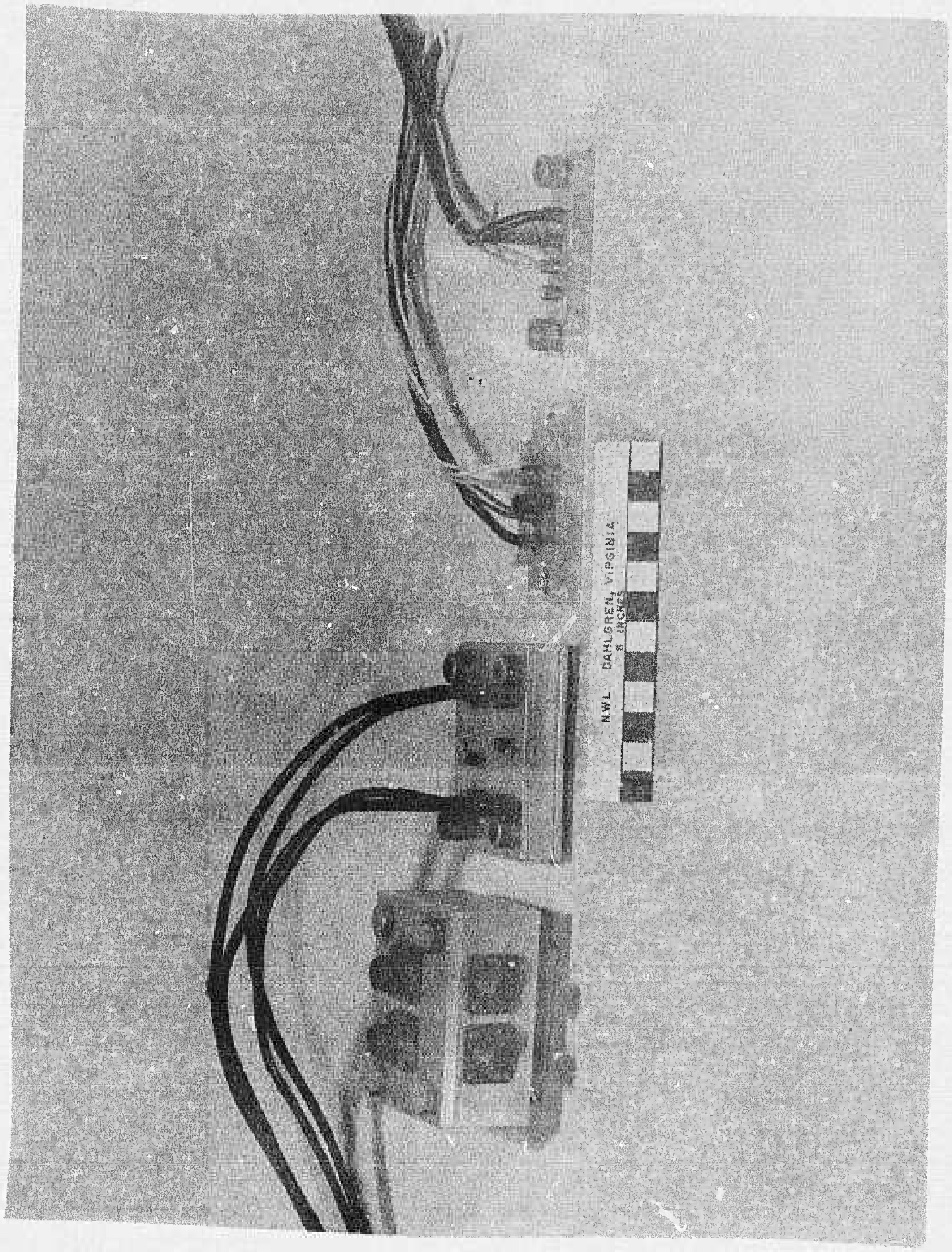


Figure 42

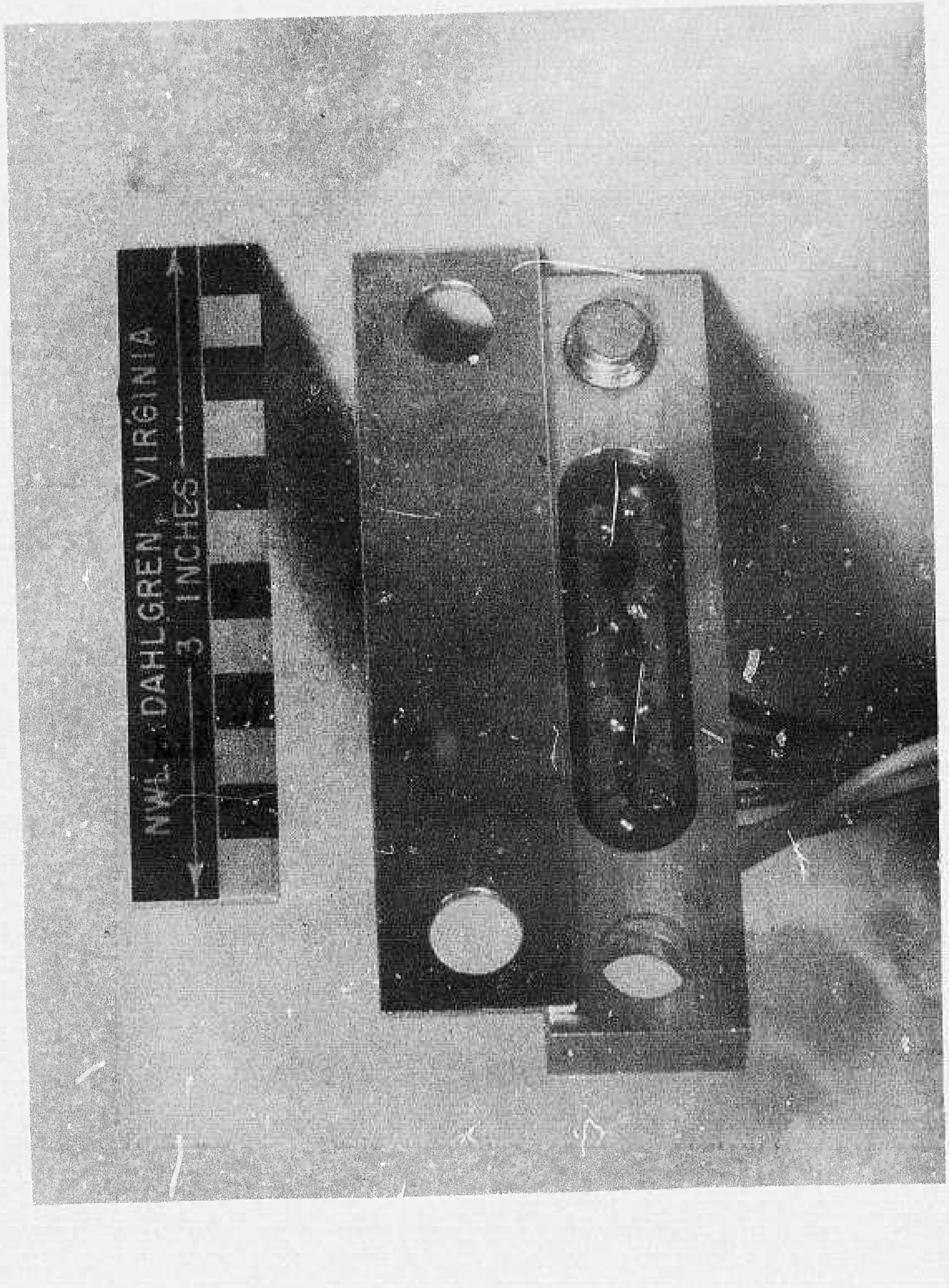


Junction Box

Figure 43

External Configuration of FMU-118A and 119A
Electric Detonators

Figure 44



Printed Circuit Board

Figure 45

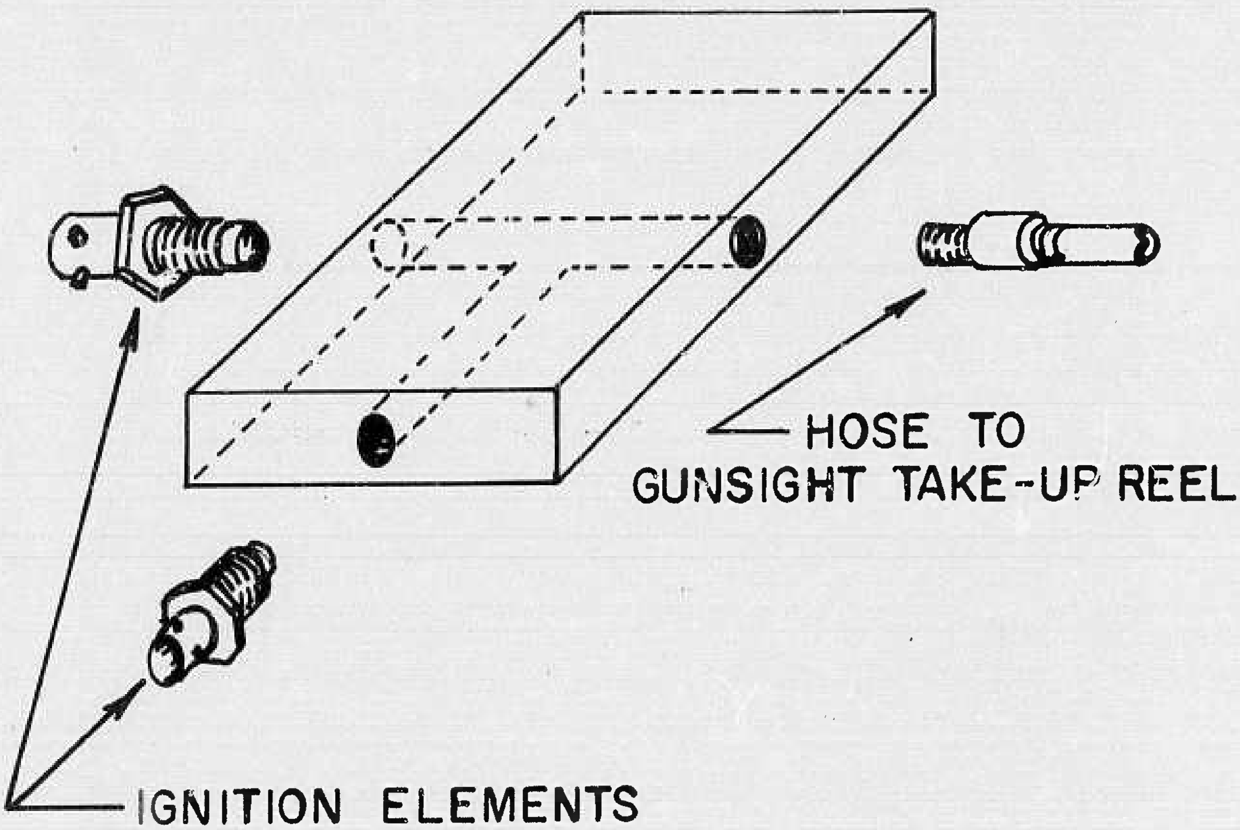


Figure 46

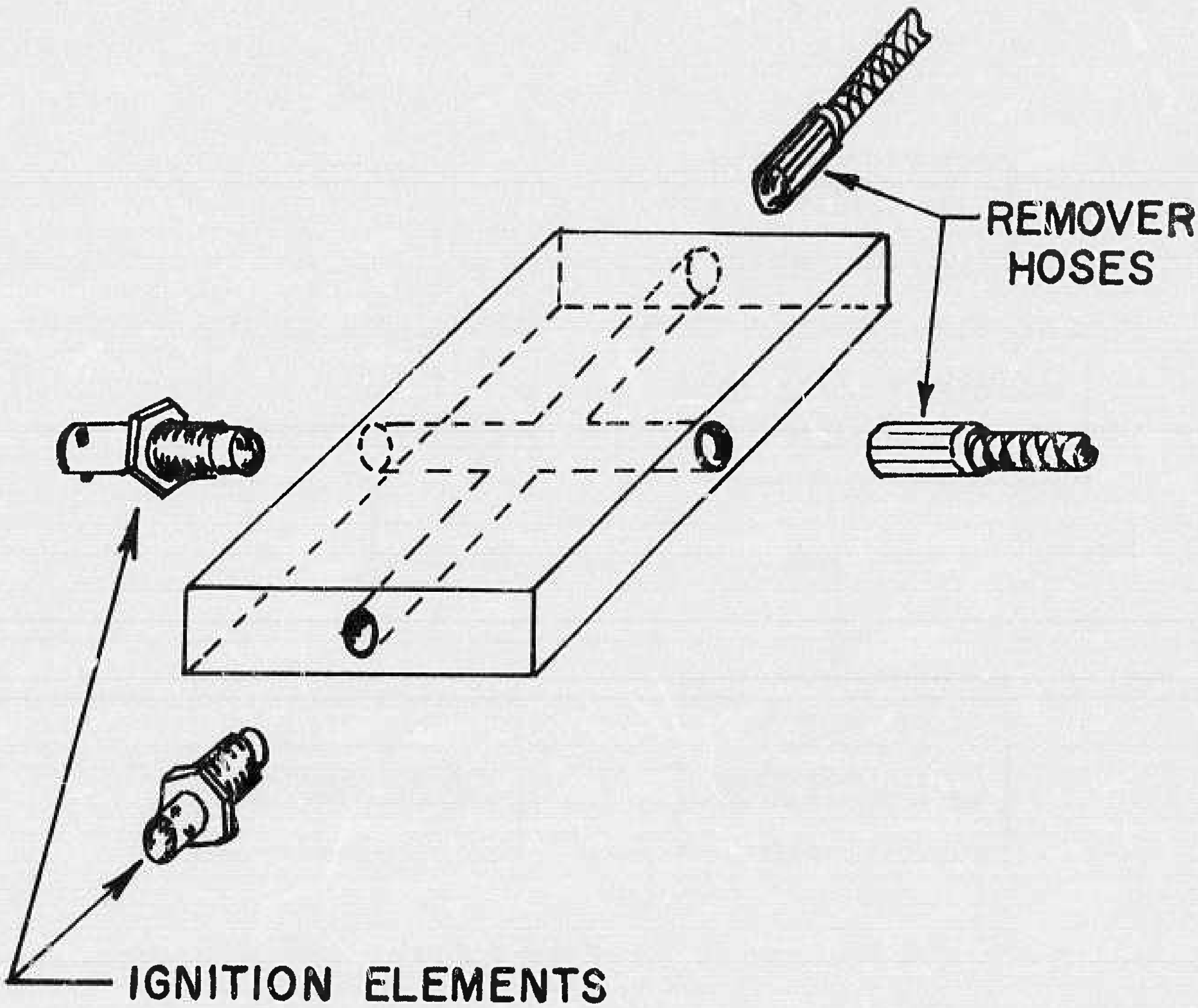


Figure 47

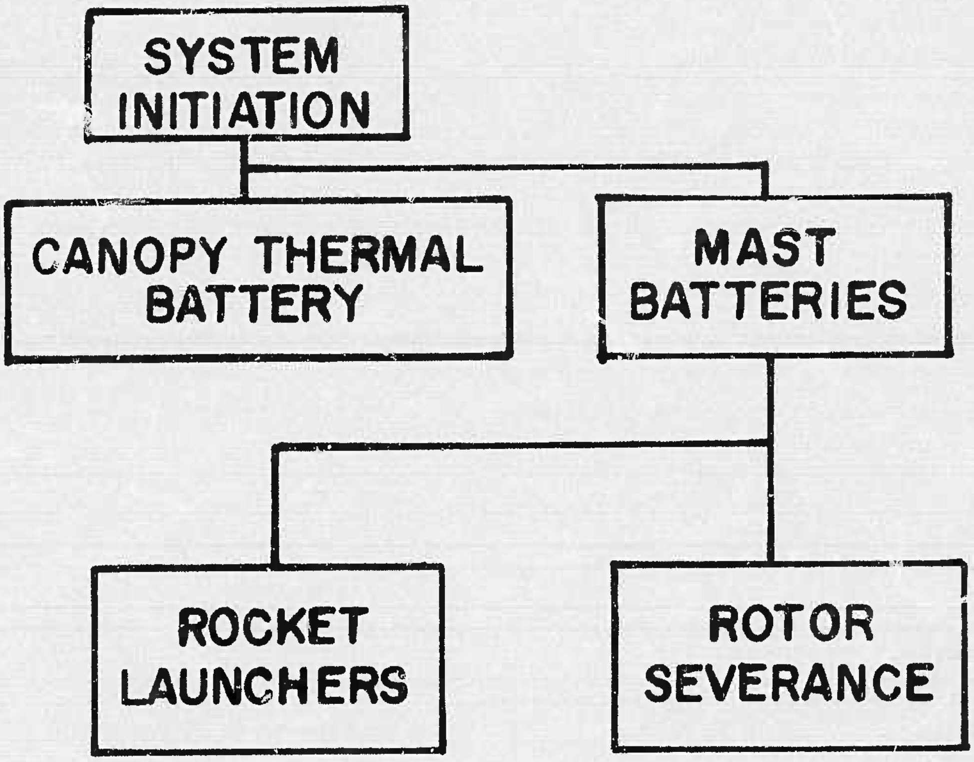

SYSTEM INITIATION
CANOPY THERMAL BATTERY
MAST BATTERIES
ROCKET LAUNCHERS
ROTOR SEVERANCE

Figure 48

APPENDIX A

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Naval Surface Weapons Center, Dahlgren Laboratory, was responsible for development of the ballistic subsystem of an in-flight extraction escape system which is to be retrofitted into the AH-1 helicopter.

Work was done in the following areas of the ballistic subsystem: (1) rotor blade severance, (2) canopy jettison, (3) gunsight retraction, (4) launcher for the extraction rocket, (5) lap belt release, and

(6) initiation, sequencing and energy transfer. Also a computer program was prepared to simulate the extraction of the crewmen from the stricken helicopter. It was demonstrated that (1) the canopy can be jettisoned at aircraft speeds up to 170 knots, (2) rotating rotor blades can be severed both in a hover mode and at 150 knots forward speed, and (3) the extraction rocket can be launched successfully at speeds up to 150 knots.

The trajectories of the crewman were mathematically simulated and data generated were used in extraction tests. A design of an initiation, sequencing and energy transfer assembly was prepared using off-the-shelf components where possible. The design of the assembly will allow it to be retrofitted into the AH-1 with minimum changes required to the aircraft.